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Peat Land in the Pacific Coast States In Relation to Land and Water Resources

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Miscellaneous Publication No. 248

United States Department of Agriculture
Bureau of Chemistry and Soils

UNITED STATES DEPARTMENT OF AGRICULTURE

MISCELLANEOUS PUBLICATION No. 248

Washington, D. C.

October 1936

PEAT LAND IN THE PACIFIC COAST STATES IN RELATION TO LAND AND WATER RESOURCES

By A. P. DACHNOWSKI-STOKES, *physiologist, Soil Survey Division, Bureau of Chemistry and Soils*

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INTRODUCTION

This publication presents the results of investigations carried out in California, Oregon, Washington, and parts of Idaho in the interests of a regional approach in the utilization of peat land and the conservation of water supplies.¹

¹This study was made possible through the cooperation of the U. S. Soil Conservation Service. In the preparation of the report use was made of maps, records, and surveys of various Federal bureaus and State agencies. The illustrations, plates 1, *B*; 2, *A* and *B*; and 3, *B* are from an unpublished report by the late O. V. P. Stout, Bureau of Agricultural Engineering, and plate 3, *C*, is used by the courtesy of W. L. Powers of the Oregon State College of Agriculture. The vertical cross sections of many peat deposits and the collection of representative samples of peat, muck, and commercial peat products were made possible through the cooperation of State institutions. Special acknowledgment and appreciation of assistance received is expressed to S. C. Vandecaveye and D. J. Crowley, Pullman, Wash.; R. E. Bell and H. W. E. Larsen, Moscow, Idaho; W. L. Powers, Corvallis, Oreg.; and C. F. Shaw, S. Cosby, and M. H. Lapham, Berkeley, Calif. Cooperation from L. C. Wheeling, Pullman, Wash., during the field work in Washington and Idaho was especially valuable. Much assistance was obtained also from private individuals and agencies not listed and from I. C. Feustel, of this Bureau, who aided in sounding most of the peat deposits and in collecting large samples for profile analyses.

The field work had for its primary object a study of the inherent physical features of the various peat areas on the Pacific coast. It included the identification of the several layers of organic material that constitute a peat deposit and examination of conditions pertaining to agricultural development, the production of commercial peat products, and water supplies.

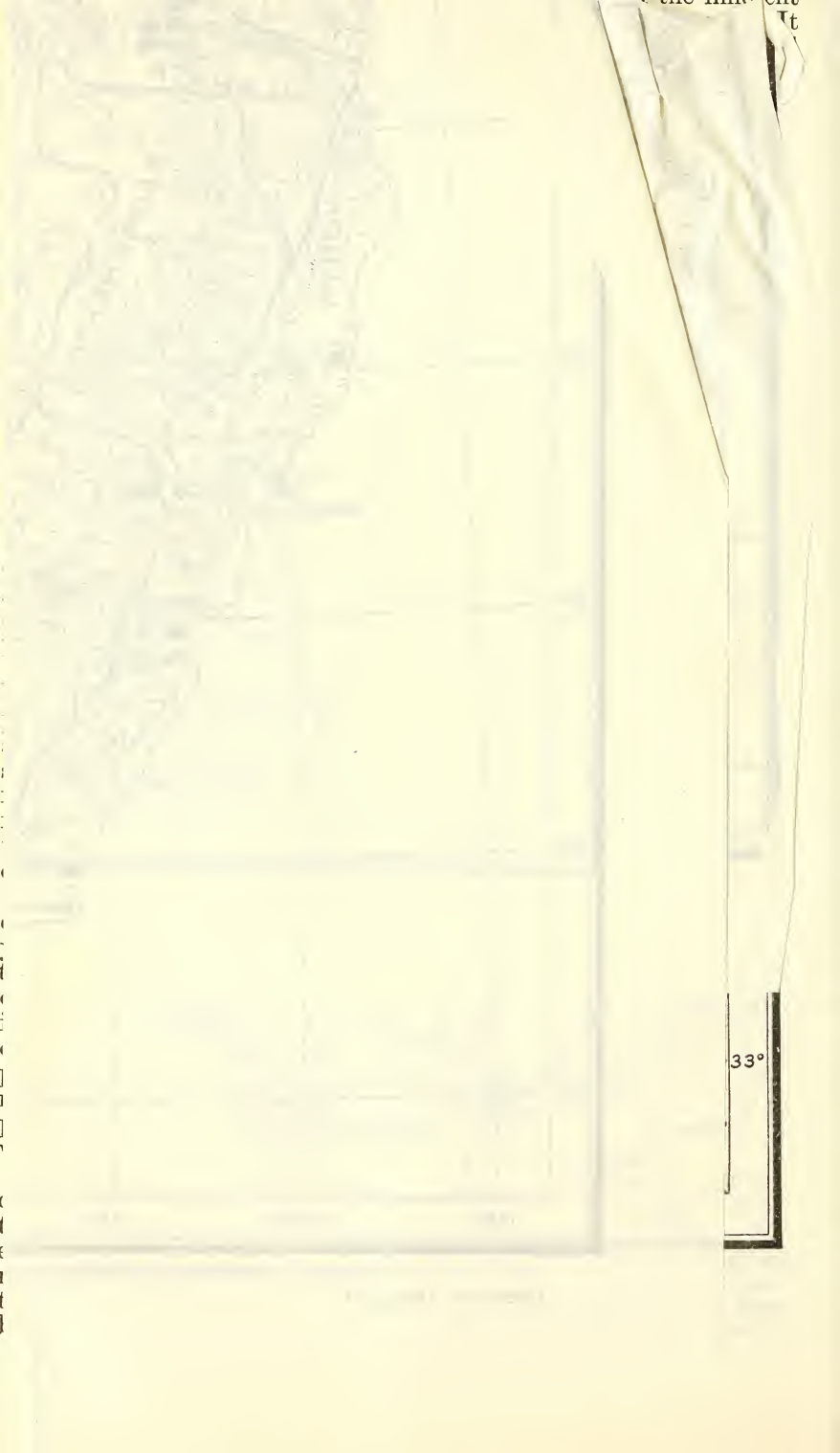
Special emphasis was laid upon the problem of water conservation because of the long-continued decline of the ground-water table in most of the southern Pacific coast section and because of the important place that storage of flood waters and the control of stream flow, erosion, and salinity have come to play in the States that are dominantly semiarid. Ground water is a resource equally as important as the supply of surface water, because it limits the productive capacity of both mineral and organic soils. Drainage of peat land has helped to lower the ground-water table and added greatly to an ever-increasing demand for water in irrigation. Lowering of water levels in peat deposits has seriously diminished a supply of water that accumulated through ages, as well as from the melting glaciers and waning ice sheets of the last glaciation. It is threatening the maintenance of a vegetative cover that was effective in slowing down stream flow and reducing erosion and silting.

On the basis of these facts consideration must be given to the water resources of the Pacific coast and their control. Very much depends on how the water supply from various sources is conserved. Around Puget Sound and along the northern coastal section to San Francisco the rainfall is usually adequate for agriculture, and flood problems are more or less urgent. But southward and inland, precipitation declines rapidly and shortages of water are more serious by comparison. Practically no rainfall occurs in the warm dry period between May and September, and irrigation of crops is necessary in certain areas throughout a considerable part of the growing season as well as in winter. In the coastal and elevated inland mountain ranges, rainfall is higher, springs are frequent, and stream flow in general discharges through steep and rocky canyons onto the valley floor below. During the summer, rainfall and stream flow diminish greatly at a time when the demand for water is greatest.

Variations in rainfall on the Pacific coast are more or less periodic or cyclic, a series of wet years being followed by a series of dry years. Although fluctuations in run-off and flood waters are erratic, they closely parallel the periodic occurrence of precipitation. Storage of water in basins and depressions, in porous organic materials, and in pervious mineral soils constitutes, therefore, an important source of supply of ground water for irrigation and a significant aspect of protection from flood. As yet, little has been done toward supplementing the water-storage capacity of peat land in the valleys or to provide measures and uses of peat deposits for the conservation of water resources at the boundaries of watersheds.

Protective functions against floods, erosion, silting, and the accumulation of so-called "alkali salts" and measures for the conservation of rainfall and water supplies are not simply geologic nor engineering problems. The solution lies in part in reestablishing natural plant communities on overdrained peat areas that are subject to fires and wind erosion, on lake beds of peat deposits that have been damaged by an accumulation of salts, and on peat land that is





33°

difficult to drain and protect from overflows or is physically and economically unprofitable for agriculture. The hope of high returns, without a study of the character of the peat area and the cost of crop production, has led to disappointment for many. Preservation of ponds, sloughs, marshes, and swamps should be considered, wherever such areas are desirable for restoring wildlife and former ground-water levels. Utilization should be made of all possible and promising sites on watersheds, in foothills, and in valleys, for the development of peat-forming vegetation that contributes organic material of high water-absorbing and water-storing capacity, and holds back run-off, thereby reducing the carrying power of water, the rate of erosion and flood damage, and silting. It is not generally recognized that ground-water supplies are exhaustible and that their adequate yield over long dry periods or through cycles of wet and dry years is dependent in large part on the quantity of water that percolates into the ground from peat deposits, streams, marshy lakes, swamps, and other natural reservoirs of rainfall and flood waters. There are many areas of drained peat land throughout the Pacific coast region in which the water tables have dropped and crop yields have been reduced. These are now being abandoned. It is generally realized that under present economic conditions, conservation of water and restoration of wildlife should be given greater consideration.

More than 800,000 acres of peat and muck have been mapped by the United States Soil Survey in widely separated parts of the Pacific Coast States. The deposits occur at elevations ranging from near sea level to high plateaus and alpine altitudes. It is believed that the conditions described and the profiles presented in this publication by number (in parenthesis) and name, and shown on the map (fig. 1) by a corresponding number, are characteristic of areas of peat land throughout the Pacific coast section, and that the data and findings provide information for a more effective development of the peat deposits as land and water resources.

PEAT LAND IN THE SOUTHERN PACIFIC COAST SECTION

The southern Pacific coast section is characterized by greatly varying topography and by similarly varied rainfall and ground-water supplies. The principal rivers are those draining the west slope of the coastal mountain ranges. The flow of most of the streams originates in the foothills, depends almost wholly on rainfall, and is intermittent and meager in quantity from May to October. Coastal streams originating at higher altitudes are fed in part by melting snow and have a more continuous flow.

In discussing the peat deposits of the section and their different characteristics, the following descriptions will be related to geographic divisions based in general on those used by the Soil Survey Division and by the Water Resources Branch of the United States Geological Survey.

The location and acreage of many of the valley peat deposits have been published in previous reports by the Bureau of Chemistry and Soils cooperating with the California Agricultural Experiment Station. Future investigations in the mountain ranges and national forests may bring to light areas of peat as yet not recognized. In

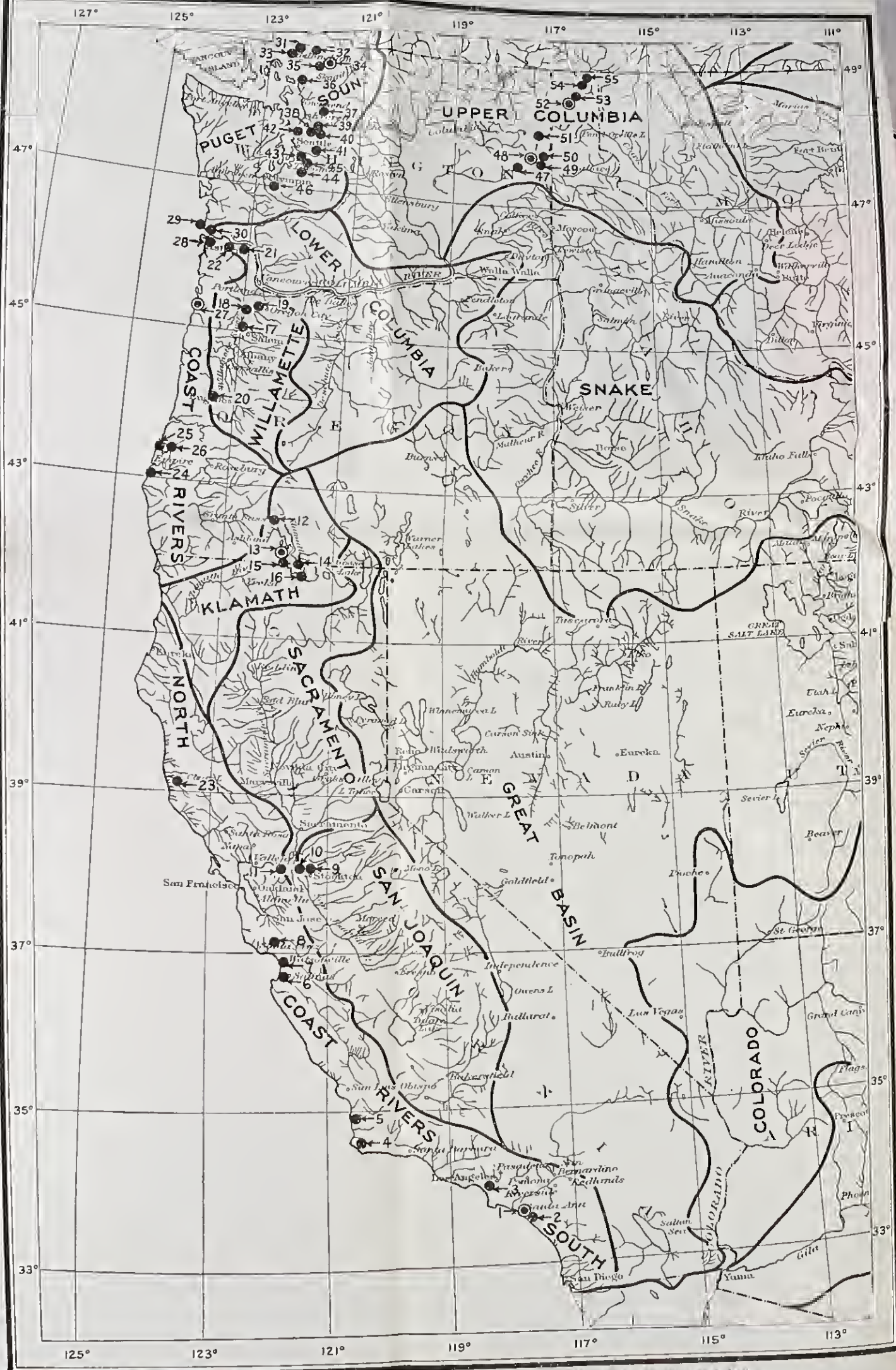


FIGURE 1.—Numbers and approximate location of profiles of peat soundings in the Pacific Coast States.

mapping the vegetative cover, undertaken by the California Forest and Range Experiment Station of the United States Forest Service, an endeavor is made to establish not only the beneficial effects of marshes, bogs, and swamps in retarding run-off on forested watersheds, but also to establish the relationship between natural plant communities and the respective peat profiles.

The peat deposits in the valleys of this section are in few places, if anywhere, of uniform structure throughout. Generally they consist of several layers of peat differing greatly in thickness, composition, texture, permeability, and, therefore, in their properties of absorbing and retaining moisture and soluble salts. The water-storage capacity of a peat deposit in any region and the mechanism of its water movement are determined by the character and the sequence of the layers it contains, as shown by a vertical cross-section, or profile, of the area of peat. Permeable layers, such as fibrous or woody-fibrous reed or sedge peat and moss peat, that lie below the surface of an undrained deposit, are more or less saturated with water. Changes in the quantity and movement of water are accomplished largely through gravity and capillarity. In finely divided impervious organic materials, such as sedimentary and sedimentary-fibrous types of peat, and in organic residues that are colloidal in character, the forces controlling the water content are mainly those associated with colloids. Methods relating to physical analyses have been described in Technical Bulletin 214 of the United States Department of Agriculture (12).²

Differences in the character of the principal classes of peat and differences in the origin and structure of peat land are of great importance not merely in the storage of adequate water supplies. For agricultural and industrial purposes it is equally important to take into consideration the character and arrangement of the several layers of peat. The possibility of crop yields depends partly on the changing composition of the organic materials, that is, on the physical properties that limit decomposition, water content, the quantity of nutrients liberated, the variety of micro-organisms which bring about different reactions, and partly on modifying conditions and factors that influence economic considerations. Quite apart from these, a modified water table causes damages of the most serious character. In consequence, it is of vital interest to know the features of the peat profile—the inherent changes from porous and permeable materials, light in weight and high in absorptiveness, to comparatively dense and impervious layers heavy in weight, variable in absorptive capacity, and subject to marked shrinkage and hardening when overdrained or air-dry. Field studies and historical records are called for to provide a basis for the proper use of peat areas in the management and rehabilitation of land and water resources.

The coast ranges of the southern Pacific section include a number of large fertile valleys lying between San Francisco Bay on the north and Orange County on the south. Profile soundings of peat land representing this section of the coast were made in the valleys of the Santa Ana, Santa Ynez, Santa Maria, Salinas, and Pajaro Rivers.

² Italic numbers in parentheses refer to Literature Cited, p. 66.

PROFILES IN THE SANTA ANA VALLEY

The Santa Ana Valley is a part of the drainage area including Santa Ana, San Gabriel, and Los Angeles Rivers which drain the coastal parts of Riverside and San Bernardino Counties, nearly all of Orange County, and a part of Los Angeles County. The 10- to 15-inch annual rainfall in the valley, combined with high temperatures, creates semiarid and subtropical conditions. In the mountainous part of the watershed, the average annual rainfall is nearly 30 inches, the greater amount of which occurs from December to March. The mean annual run-off is estimated at 446,000 acre-feet of water, a large part of which percolates into the gravel fills underlying the valley floor and constitutes an underground water supply that slopes toward the ocean. Floods are occasional and generally the result of sudden downpours. Because of the recurrence of destructive forest fires in the past, the vegetative cover in the mountains has had, as yet, little influence in checking the flow of streams. During flood stages the water flows in numerous unstable channels and is, in part, wasted, carrying soil brought down by the streams and tributaries that rise in the San Bernardino Mountains. Much of this moisture helps to restore the ground-water table. In the flat coastal plain the peat areas contain more or less alkali salts in places.

In the soil survey of the Anaheim area (11) the extent of peat and muck is given as 1,024 acres. The greater part occupies small, in general elongated, depressions in the alluvial stream bottoms and poorly drained margins of alluvial fans. Other peat areas lie adjacent to bluffs of the old coastal plain and are affected by seepage water. A few are covered with a 10- to 16-inch deposit of river wash brought in by silt-laden flood waters. Practically all the peat areas were formerly cultivated, mainly to a diversity of truck crops in small plantings. Several bodies of peat land are seriously affected by drought and salinity, and some of them are now utilized for commercial purposes to supply the requirement of organic matter for orchards, lawns, and landscape gardening.

The peat deposits that were examined for profile features occur southwest of Wintersburg, near Westminster, Talbert, and Smeltzer, and at Huntington Beach. They are typical of peat land occurring elsewhere in this valley.

(1) WINTERSBURG PROFILE

The deposit represented by this profile is in the NE $\frac{1}{4}$ sec. 27, R. 11 W., about 3 miles north of Huntington Beach, Calif. It comprises 190 acres, much of which has been brought under cultivation. Within recent years a large part of this area has been developed industrially for commercial peat products. A considerable tonnage of raw tule peat has been removed by means of a clamshell dredge (pl. 1, A). Excavated sections store water from rainfall during wet seasons, and they support aquatic plants, such as *Lemna minor* L., *Azolla* sp., *Myriophyllum spicatum* L., and pond weeds (*Potamogeton* sp.); scattered patches of marsh vegetation consisting of cattail (*Typha angustifolia* L.), sedges (*Cyperus* spp., and *Carex* spp.), and rushes (*Scirpus americanus* Pers., *S. validus* Vahl., *Eleocharis* spp., and *Juncus* spp.); and bordering the ponds are a few deciduous

shrubs and trees including willow (*Salix nigra* Marsh. and *S. laevigata* Bebb.).

The peat profile is three-layered, indicating the usual sequence of development. It consists of a basal layer of organic sediments that accumulated in deep water from aquatic vegetation; overlying this sedimentary-fibrous peat, produced by an encroaching amphibious-plant community; and the surface layer of fibrous peat accumulated from plants common to marshes that covered the entire lake and continued to grow upward. A more detailed study of vertical cross sections shows the following features:

0 to 6¾ feet, tule peat. The surface material under cultivation consists of well-decomposed organic residue to a depth of 18 inches; it is dark grayish black, granular, and friable and contains saline incrustations and silt from flood waters. The material below is dark-brown matted fibrous tule peat, neutral to slightly acid (pH 6.5-7)³ in reaction. It consists chiefly of an interwoven network of roots and underground stems. Between depths of 3 and 4 feet this material grades sharply into reddish-brown or yellowish-brown coarse-fibred and porous tule-reed peat. At a depth of 6½ or 6¾ feet the layer includes an admixture of gray silty clay suggestive of floods of major proportions, probably a result of former geologic changes.

6¾ to 13 feet, sedimentary-fibrous peat. A brown or dark-brown mixture of moderately decomposed stringy-fibred sedge peat derived from roots and rhizomes of tule. This layer is more or less pervious but is firm and has embedded in it varying quantities of sticky, plastic, organic, ooze-like material including diatoms.

13 to 17 feet, sedimentary peat. Very dark brown or black finely divided organic sediments, neutral in reaction, dense in structure, compact and colloidal in character. This layer contains diatoms, leafy material from pond weeds, seeds of waterlily, and, at the lower level, small shells from univalved mollusks.

The underlying mineral consists of gray or dark-gray sandy silt containing fine particles of mica.

(2) TALBERT PROFILE

East of Talbert, Calif., is an area of peat with morphological profile features showing layers that are strikingly similar in sequence and appearance. The profile is a variant, however, in that the surface material, to a depth of 18 inches, consists of gray micaceous sand deposited as overwash by flood waters within recent years. The mineral soil (Hanford series) overlies a thin seam of very dark brown organic residue and has embedded in it the stems of the former tule marsh vegetation. The underlying fibrous tule peat is essentially like that described for the Wintersburg profile, but the layers of sedimentary-fibrous and sedimentary peat contain several bands of micaceous silty sand. The deposit is 14 feet thick and is being excavated for commercial purposes.

In this connection the results of certain laboratory work deserve attention. It has been shown that fibrous sedge-reed peat absorbs more than 7 times its own weight of water (12). Expressed in quantity of water absorbed per acre-foot of dry organic matter, the absorption capacity is equivalent to about 4,000 tons, or to a volume of about 115,000 cubic feet of water per acre (10). The California State Department of Public Works has long realized the importance of a program for the conservation of water. To this end studies

³ Determinations made in the field by I. C. Feustel with colorimetric methods. Profile soundings were made with the American peat-sampling instrument.

have been made on evaporation and transpiration (1) which deserve extension under a unified plan that will make comparison on a regional basis possible. However, to save losses of water evaporated by a native plant cover may not help the water problems in the coastal valleys. Peat-forming vegetation holds back more of the rainfall than cultivated crops and has better water-storing capacity than mineral soil. The intrusion of salt-laden waters and the consequent injurious concentration from tidal and seasonal encroachment of salinity are damaging drained areas of peat as well as the mineral soils in this section of the coastal plain. Toxic excesses of salts can be prevented by keeping at a high level the water table of peat land near the ocean.

PROFILES IN THE LOS ANGELES VALLEY

The preceding discussion on the problem of water conservation in the Santa Ana Valley should be considered also in connection with the Los Angeles Valley.

It is estimated that about 10,000 acre-feet of water are lost annually from transpiration and evaporation in marsh areas, such as that bordering Ballona Creek east of Culver City. This deposit of peat lies in a flat, nearly level, depression in the alluvial plain. Considerable drainage has already been accomplished over part of the peat area, and the water table lies at a depth of more than 5 feet below the surface. Injurious quantities of alkali have accumulated over parts of the area, and fires and wind erosion have, in some places, removed practically all the organic matter.

(3) CULVER PROFILE

An exposed vertical profile (the Culver profile) was observed at a point 500 feet south of the terminus of Houser Boulevard. In that section a small amount of peat is excavated and utilized as a source of organic matter for the improvement of mineral soils. The profile is one-layered and shows the following features:

0 to 60 inches, sedimentary muck. The cultivated surface material, to a depth of 10 inches, consists of dark brownish-gray loamy muck readily penetrated by roots of growing plants. The organic residue is granular, friable, moderately high in silt and sand, and slightly alkaline in reaction (pH 7.5).

The underlying material is black sedimentary peat, fairly compact and fine textured to a depth of 29 inches below the surface. It grades into stratified, grayish-black organic sediments containing diatoms and thin bands of silt from intermittent overwash; the lower part of the layer is more colloidal and continues so to a depth of 5 feet. Cracks and fissures appear at the bottom level in many places, owing to dryness of the peat and its shrinkage from excessive lowering of the water table. The underlying mineral substratum is sharply demarked and consists of yellow sand, mottled here and there with root channels.

The principal crops grown are grain, hay, and grasses, and yields are usually fair. Truck crops are grown to some extent where water can be applied by irrigation. In alkali-affected sections of this area the crops are stunted and discolored. Some bare spots occur, and small depressions contain standing water. In some places the layer of sedimentary peat is less than 3 feet thick, and in others it has been burned off completely during dry seasons. Conditions such as these

are unfavorable to the present use of the peat area, and they give no promise of lasting benefit. Conservation for purposes of improving the storage of flood waters may be a more appropriate use for the 1,088 acres of peat and muck mapped by the Soil Survey in the Los Angeles area (27).

PROFILES IN THE SANTA YNEZ VALLEY

Santa Ynez River is the principal outlet of a drainage basin that includes steep slopes and semiarid wooded hills. No stream flow is recorded during part of the year, and much of the run-off in the rainy season is diverted for municipal uses. The burning of chaparral has denuded many slopes, modified the run-off, and brought about the silting of reservoirs, and other damages of a serious character. To insure natural recovery of the wooded hills in an adequate degree, extensive districts have been sown with seed of woody herbs by Civilian Conservation Corps crews.

In this area, the Soil Survey Division (6) has mapped only one deposit of peat, comprising 512 acres. It lies west of Harriston and occupies a low, poorly drained depression—the result of a dike of resistant rock that obstructed drainage of San Antonio Creek. At present the area is undeveloped and more or less inaccessible. The southern half of the deposit is covered with a dense growth of willows and deciduous brush, and the northern part supports tule, sedges, and other plants that thrive under conditions of a high water table.

(4) HARRISTON PROFILE

The relation between the native cover of vegetation and the peat profile was observed at an outlet that had been dredged recently, in order to provide drainage preparatory to clearing the wet marsh and shrubby swamp. A vertical cross section exposed in the open ditch, showed an overburden of dark grayish-brown mellow mineral material, 18 inches thick, overlying a few inches of gray sandy silt. Below this the profile features have the following characteristics, representing a one-layered accumulation of plant remains:

0 to 50 inches, sedimentary peat. The upper part of the layer, to a depth of 21 inches, consists of dark grayish-black sedimentary peat, fine textured, moderately heavy and compact, tending to take on an adobe structure and to break irregularly when dry. The lower part, between depths of 21 and 42 inches, consists of light-gray or gray calcareous organic sediments which are gravelly at the lower level. The underlying material is brown or gray-brown sandy organic residue which is compact and ranges from 25 to 35 inches in thickness.

This peat land is not potentially valuable. It is subject to flooding, and its protective value—at least with a view to water resources and as wildlife refuges—should be an important deciding factor in its conservation.

PROFILES IN THE SANTA MARIA VALLEY

In the western part of Santa Maria Valley, not far from the ocean, lies the only body of peat mapped in this area by the Soil Survey Division (40). It is shut off from the ocean by large stabilized sand dunes and occupies a shallow basinlike depression along the channel of a creek that is subject to overflow each year. The creek is a tribu-

tary joining the lower end of Santa Maria River, cutting through the sand dunes to reach the ocean. The run-off of the main river is erratic, and no flow occurs normally from June to November of each year except, possibly, during storm periods.

(5) SANTA MARIA PROFILE

The peat area examined was originally a marsh without drainage, which supported a growth of tule, cattail, sedges, rushes, and aquatic herbaceous plants. It extends in an east-west direction and comprises 320 acres. The peat land is now under cultivation, but a large part is bare of vegetation, and its further agricultural use has been abandoned. Profile sections show the following features, indicating in part the modifying conditions associated with the abandonment of the tract:

- 0 to $3\frac{1}{2}$ inches, tule muck, the surface material of which is dark grayish black in color, largely in an advanced state of decomposition, granular, and strongly acid in reaction (pH 4 to 4.5). The organic residue contains sand blown from the dunes, and large quantities of crystals of calcium sulphate. Fires, that burned the fibrous tule peat from many acres, added to the organic material a red-colored ash.
- $3\frac{1}{2}$ to 8 inches, black or grayish-black sedimentary-fibrous tule peat which is moderately compact, sticky when wet, and mottled with small clusters of gypsum crystals. Root channels, stained rusty red and coated with crystals, are common. This layer includes a thin band of light-gray silt at a level of 5 inches below the surface, and below this is black sticky organic residue of adobelike structure.
- 8 to 11 inches, clayey silt, suggestive of overwash, which is light gray with a brownish tint and contains numerous vertical root channels in addition to rhizomes of tule and cattail in a horizontal position, all of which are coated with crystals of calcium sulphate and a yellow salt. The reaction of the peat material is acid (pH 5).
- 11 to 14 inches, dense, impervious, black sedimentary peat containing two thin bands of gray silty overwash. At the lower level the material is mottled with root channels and crystals of gypsum. It is fairly sharply demarked from a mixture of organic residue and light buff-colored dune sand that contains root channels of a rust-red color and long needles as well as small clusters of calcium sulphate. The reaction is acid (pH 5).
- 14 to 24 inches, light-gray dune sand, only slightly stained with root channels or organic residue. Evidence of salinity or effervescence with hydrochloric acid has not been determined.

Specific data pertaining to stream flow and salinity are not available. Any plan providing for the control of salinity should have under consideration the means of water storage. The peat area should be developed as a reservoir to exclude the effects of tidal action and to prevent an accumulation of salt in adjacent soils.

PROFILES IN THE SALINAS VALLEY

The Salinas area mapped by the soil survey division (4) includes 2,880 acres of peat land in the alluvial lowland drained by Salinas River. This stream and several smaller tributaries empty into Monterey Bay. A number of areas of peat occur at points where drainage has been blocked or impeded, a few of them occupying basinlike depressions, and some lying along sloughs and meandering streams, that have been modified by erosion and deposition.

The maximum discharge of Salinas River is in December, and there is no surface flow from July to October. Such long-term rec-

ords of run-off as are available (15) indicate periods alternating between greater and less stream flow and, therefore, of rainfall.

The more extensive areas of peat land occur northwest of Salinas, and a rather large deposit occupies the basin of former Merritt Lake. Under natural conditions they are waterlogged marshes occupied by tule, reed, cattail, and tussocky rushes and sedges. Where drained the land is subject to fires and to accumulation of an excess of soluble salts, or "alkali." The areas are used preferably as pasture for dairy cattle and other livestock, and a small acreage is used in the production of vegetable crops. Onions yield from 200 to 250 bushels an acre on muck low in salinity, and on lighter, more fibrous peat, potatoes and other truck crops do equally well with the application of mineral fertilizers carrying potash and phosphoric acid.

(6) COOPER PROFILE

The area of peat examined is about one-half mile northeast of Cooper, east of the Southern Pacific Railroad. The tract has been under cultivation, but it is only moderately productive. It represents contiguous peat land where conditions are comparatively unfavorable to agricultural crops. A profile showed the following features:

- 0 to 12 inches, tule-reed muck, the cultivated 8-inch surface material consisting of very dark grayish-brown or grayish-black muck, much of which has an admixture of fine mineral soil washed in from adjacent slopes; it overlies denser material which shows a characteristic adobe structure at the lower level and breaks into irregular small angular granules.
 - 12 to 16 inches, yellow-brown predominantly coarse-textured fibrous tule-reed peat compacted to a laminated or platy structure. The material is nearly air-dry and is fissured by cracks caused by shrinkage. The layer represents a former floating mat that is reported to have been 2 or more feet thick under natural waterlogged conditions.
 - 16 to 24 inches, dark-gray or grayish-black dense fine-grained clayey organic sediments embedded in considerable brown fibrous material that is derived from roots and rhizomes of tule and cattail. In structure and other characteristics, this material approaches sedimentary-fibrous peat.
 - 24 to 30 inches, gray or dark-gray impervious clayey organic sediments which are sticky when wet. Under excessive drainage the material is cloddy when dry and breaks into a mass of jointed angular particles.
- The mineral substratum is grayish-drab clay or silty clay, mottled in places with rusty-colored material.

Because of its physical and economic limitations, large acreages of this type of peat land should remain undrained and should be utilized chiefly to impound run-off of surface water during winter and to conserve moisture, the waste of which would otherwise produce detrimental effects on the ground-water supply.

PROFILES IN THE PAJARO VALLEY

The Pajaro Valley, lying about 100 miles south of San Francisco, is almost entirely enclosed by the Santa Cruz Mountains. It is divided into two unequal parts by Pajaro River which enters from the east through a narrow defile in the mountains. From the low hills on the northern side of the valley, several small tributaries flow southward into Pajaro River. Run-off is high in the rainy season, but there is no flow during the late summer months. The length of these periodic variations is not well marked. Recurrence of periods

of low rainfall has given rise to decreased stream flow and to inadequate water supply, making irrigation and water conservation more or less essential.

An area of 1,216 acres of peat land has been mapped by the Soil Survey Division (23) along Larkin Creek and its branches, among the low hills west of Watsonville. This peat land occurs in drainage channels and depressions of varying depth and owes its origin to the restricted drainage caused by deposits of alluvial soil that were brought down in floods by Pajaro River and deposited across the mouth of Larkin Creek near tide level.

(7) LARKIN PROFILE

Structural features of the Larkin peat profile are represented by soundings made about 2 miles west of San Andreas School, along the highway to Ellicott, which crosses the peat deposit. The area was originally a lake that developed into a wet marsh of tule and cattail, subject to surface flooding. By cutting drainage ditches to tide level, much of the land has been brought under cultivation. However, gravity drainage is not sufficient on peat land near sea level. Yields of truck crops decline, owing partly to uncontrolled fluctuations of the water table during the wet season and partly to the presence of salts that accumulate on the surface as incrustations during the dry growing period.

The profile features which differentiate this peat area from other deposits as a recognizable type show the following characteristics:

- 0 to 14 inches, tule muck. An 8-inch surface material consisting of dark grayish-black coarsely granular cultivated organic residue developed from tule and cattail peat and grass sod plowed under. The subsurface material is well decomposed and friable but contains an appreciable quantity of salty incrustations, and the material below is dense sticky wet organic residue which hardens when dry and breaks into small angular lumps and granules.
- 14 to 17 inches, dark-brown moderately decomposed woody-fibrous tule peat, in which the woody fragments are derived primarily from a shrubby growth of willow. Charred material in this layer is suggestive of surface fires at a period when the water table was low.
- 17 to 96 inches, light reddish-brown or yellowish-brown fibrous or felty-fibered tule-reed peat mottled with black organic residue. The material includes a thin band of sticky fine-textured sediments at a depth of about 80 inches below the present surface. The material in this layer is light in weight and fairly porous.
- 96 to 168 inches, grayish-brown moderately dense and sticky sedimentary-fibrous peat containing many fine brown roots and flattened rhizomes from tule and cattail. The material at the lower level is waterlogged, loosely fibrous, and characteristic of a floating mat.
- 168 to 240 inches, rather soft and amorphous sedimentary peat ranging in color from grayish brown to black. It represents pond-formed ooze and contains diatoms, colloidal material, and bits of plant remains derived from roots and underground stems that were, probably, contributed by the overlying floating mat. The parts of this deposit below a depth of 240 inches were not sounded.

The mineral substratum along the margins consists of dark-gray sticky gritty clay containing gravel.

To date the economic success has not been so great as to call for deeper drainage of this peat area.

To assure a dependable supply of ground water for adjacent mineral soils, it is necessary to stabilize water levels. The preservation of this peat deposit should be recommended. The low, peat-

forming lakes, such as College Lake north of Watsonville, should be given consideration in supplying additional water rather than in reclaiming new peat land of doubtful value.

(8) MOUNT HERMON PROFILE

On the east side of the Pajaro Valley, the Santa Cruz Mountains extend in a northwesterly direction and include several small alluvial valleys. Some of these have grassy marshes fed by springs and bordered in part with native brush and trees, mainly oak and redwood. About 5 miles north of Santa Cruz, at an elevation of approximately 500 feet above sea level, an area of peat was sounded near the junction of the Los Gatos highway and the Mount Hermon road. The tract comprises 15 acres and is used as pasture. From a part of the area the peat is now being excavated and spread on the ground to dry. The material is prepared as a commercial organic product for soil improvement and is sold to owners of greenhouses and golf courses, and landscape gardeners in the larger cities.

The vertical cross section of the peat area is morphologically similar to the three-layered profiles described, but the respective layers are comparatively free from salts and the deposit expresses a difference in environmental conditions. The variations are sufficiently well marked to affect the practical use of the land. They are not merely incidental to the inherent character of the profile as shown by the following features:

- 0 to 11½ inches, sedge peat. The surface material consists of yellowish-brown felty-fibered porous sedge peat which is acid in reaction (pH 5) and tends to become brittle when dry. The identifiable rhizomes are slightly decomposed, and the interwoven network is penetrated by roots of the growing vegetation. This layer overlies a thin band of buff or light-gray soft, ashlike silt, probably the overwash of eroding flood waters.
- 11½ to 36 inches, dark-brown sedimentary-fibrous sedge peat charred at the upper surface. The fibrous material is partly decomposed and contains an admixture of black organic residue which gives the layer a somewhat sticky plastic character in its present waterlogged condition. It is acid in reaction.
- 36 to 48 inches, black or grayish-black sedimentary peat, amorphous in structure and pasty. This layer varies in thickness and increases from about 30 inches near the margin of the peat area to more than 9 feet in the basinlike depression where the organic sediments contain maroon-colored fragments of tule rhizomes and have a faint odor of hydrogen sulphide. The mineral substratum in most places is dark-gray sand.

DISCUSSION

To summarize, the apparent benefit to agriculture from the development of peat land in the southern Pacific coast section is comparatively insignificant. Drainage of lakes and marshes has destroyed many valuable water-storage resources and natural reserves that had a high degree of utility as supplementing sources of water supply and wildlife.

To check the rapid changes in the structure and water relations of mineral soils, there is need to increase their content of organic matter. To make possible the control of soil conditions and to meet this demand for constructive and permanent soil improvement, domestic peat industries on the Pacific coast should minimize the waste of peat resources. They should select areas of peat free from salts,

and maintain the commercial production of the better grades of peat products for use in greenhouses, nurseries, and landscape gardening, and in the packing and shipping of fruits and vegetables.

PEAT LAND IN THE CENTRAL VALLEY OF CALIFORNIA

The central valley of California is the drainage basin of the Kern, Sacramento, and San Joaquin Rivers (36). The floor of this valley is a flat alluvial plain lying between the Coast Range on the west and the Sierra Nevada on the east. The San Joaquin River drains about 18,000 square miles of the southern part, and the total drainage area of the Sacramento River is about 27,100 square miles in the northern part. Both rivers and their tributary streams have their sources mainly in the high Sierra Nevada and Cascade Mountains. They discharge by interconnecting tidal sloughs through a low-lying delta of peat land more than 400 square miles in extent and through a break in the Coast Range into Suisun Bay at San Francisco Bay.

There are only two well-defined seasons in the valley. The summer season, from May to September, is hot, with practically no rainfall. The winter season is short, mild, and is characterized by frequent rains. The mean annual precipitation, including that of the mountain areas, is about 42 inches in the Sacramento watershed and 23 inches in the San Joaquin part of the drainage basin. Seasonal variations are wide, and wet and dry years usually occur in cycles (22).

Most of the stream flow, with possible flood damage, occurs from December to March. Water from the melting snows in the upper mountain areas does not reach the stream channels until June or July. This run-off is retarded and does not contribute to large floods, partly owing to the cover of vegetation at higher elevations that aids in the regulation of flow. The mean annual run-off of the Sacramento Valley streams is computed to be about 25,000,000 acre-feet and of the San Joaquin, including Tulare Basin,⁴ about 12,000,000 acre-feet. Owing to diversion of water for irrigation, practically the entire low-water flow of the Sacramento and San Joaquin Rivers is utilized, and the mean annual flow into the delta peat lands has become less than 35,000 acre-feet in dry years.

PROFILES IN THE DELTA LAND OF THE SACRAMENTO AND SAN JOAQUIN RIVERS

In its original condition the delta was a vast, flat marsh, water-soaked and buoyant, lying near sea level. It was subject to periodic overflows at high stages of the rivers and traversed by a changing network of channels and sloughs that divided the marsh into islands (fig. 2). By the construction of many miles of levees of varying degrees of effectiveness, nearly all the marshy tracts have been drained by pumping and have been brought under cultivation. The area comprises more than 195,000 acres of peat land (17, 28) and about 1,100 miles of levees that necessitate maintenance and protec-

⁴The Tulare Basin in its original condition was a shallow marshy lake. A dense growth of tule marked the annual spread of flood waters from Kern River over a low ridge of the valley floor, into the San Joaquin Basin. The water spread in thin sheets, and the reduction in flood velocities by the tules prevented the silting of the alluvial flat that followed the destruction of the vegetative cover. Many acres of the Tulare Lake bed are now under irrigation, but a serious shortage of water renders doubtful the continued use of large areas.

tion from floods and from the eroding action of waves caused by passing vessels. Most of the material in the artificial levees is a mixture of peat and stream-laid mineral sediments dredged from the channels (pl. 1, *B*). Drainage has caused the peat islands, together with their respective levees, to shrink and settle, and in addition fires have lowered the level of the organic land until the in-

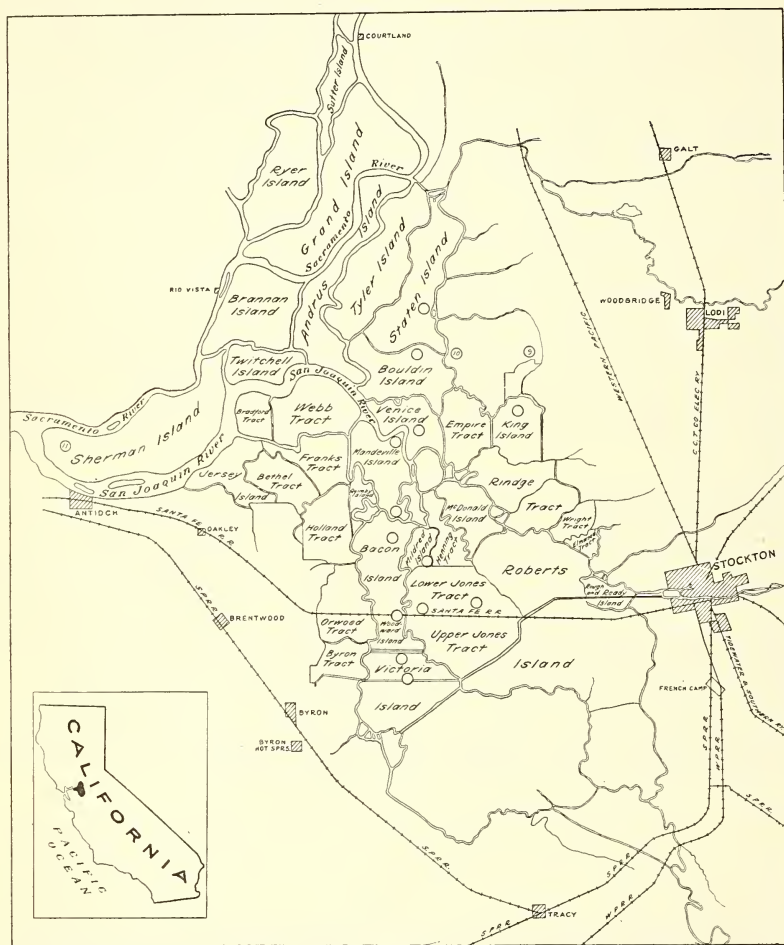


FIGURE 2.—Interlacing channels and "peat islands" in the delta of San Joaquin-Sacramento Rivers, Calif., and location and numbers of profile soundings (9).

teriors of many islands are from 6 to 8 feet below mean low-water level. The majority of levees have been raised to a height of 10 feet, and plans are being made for raising and maintaining levees at an elevation of $13\frac{1}{2}$ feet, in order to protect the cultivated tracts from unusual floods that occur about once in 45 or 50 years.

The delta peat land is an area of considerable agricultural importance. Its development began in a small way about 1860 (20). Today it is a heavy producer of asparagus, potatoes, onions, and sugar

beets. Yields are often of record proportions, and agricultural growth has been accompanied throughout by the development of industrial plants connected chiefly with canning and transporting farm products.

Irrigation is a primary need in this section. Water for irrigation is withdrawn from the channels through pipe siphons (pl. 2, *A*), by pumps, or through culverts. Fields are often flooded before planting (pl. 2, *B*), but during dry years the drafts on water in the rivers decrease the flow to such an extent as to interfere with navigation in the delta channels and to result in the intrusion of salt water (*2*) that menaces the productive capacity of cultivated tracts. Considerable areas of peat land, as well as of mineral soil, are, therefore, in a serious condition because of the decreasing water supply, the general subsidence of the peat land level and levees, and the damage to crops from salt and alkali accumulations.

The storage and conservation of water resources in the great central valley is a matter of widespread concern. It has been the subject of study by the State of California for many years, and a comprehensive plan includes the development of water storage in the mountainous areas, the construction of foothill reservoirs, and the further improvement of stream flow in the main rivers in the valley.

As a practical proposition it does not seem that much progress can be made toward the relief of peat areas in the delta until the menace of salinity and subsidence is prevented by a reasonable restoration of ground-water supplies, or until the storage of surface waters is effected through the use of peat islands as reservoirs in the delta, that will serve also the interests of flood control.

A detailed survey of the organic soils of the delta land has recently been completed by the University of California.

Soundings which have been made by the writer since 1919 and more recently throughout the delta indicate that this deposit of plant remains increases in thickness from a few feet along the eastern margin to a depth of more than 30 feet at the western end near the junction of the two rivers. They also indicate that the individual islands of peat are not uniform in character, which in turn suggests that, during the whole period of accumulation of plant remains, the water supply must have fluctuated and supported various stages of vegetation. The initial stage consisted of aquatic-plant communities and associated herbaceous plants common in open water; in later stages the area was a chain of lakes and patches of cattail and tule with dense masses of reeds, that tended to spread and finally gave way to a plant community differing but little from the aspect of the tule marsh that characterized the delta land until recently.

In the present field work, the major endeavor has been to examine areas not previously studied in detail and to differentiate the profiles on the basis of their broader inherent features.

(9) RICHMOND PROFILE

Along the eastern border, about 7 miles west of Lodi, Calif., the following profile features are exposed in an open ditch near the sheds of the Richmond packing plant. The area has produced asparagus without the application of fertilizers and is sometimes flooded before planting.

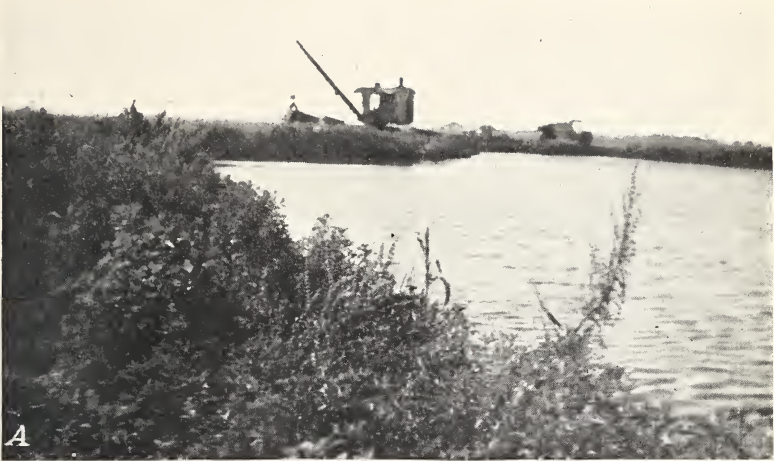
- 0 to 4 inches, tule-reed muck. The cultivated surface material consists of dark grayish-black granular residue which is slightly alkaline in reaction. It contains an appreciable amount of mineral matter, partly the ash from surface fires that are commonly set to eradicate disease-producing soil organisms. At the lower level are small quantities of less decomposed brown fibrous material and charred debris.
- 4 to 17 inches, dark reddish-brown or grayish-brown tule peat which is essentially sedimentary fibrous in character. This material is moderately decomposed, compacted, and more or less laminated in structure. It contains a variety of seeds from herbaceous marsh plants, notably buck bean (*Menyanthes trifoliata* L.) and waterlily, and at variable depths an admixture of buff-colored overwash of silty clay, together with some charred plant remains. The material in this layer is neutral in reaction and tends to crumble when disturbed.
- At a depth of 17 or 19 inches below the present surface, the silty organic matter grades into the underlying mineral substratum which consists of dark-gray fine sand and clay. The upper part of the substratum is penetrated by root channels stained rusty red.

This shallow marginal profile, designated for convenience as the Richmond profile, is moderately extensive along the eastern border of the delta. It represents characteristics that developed from a tule marsh which spread inland in rising water levels and marginal channels. When the land was drained the profile shrunk considerably, and the organic material underwent partial decomposition as a result of aeration and bacterial activity.

(10) TERMINUS PROFILE

A deeper profile, showing the distinctive features of parent peat materials, occurs about 1 mile east of Terminus. The outstanding characteristics of this profile are the alternation of sedimentary-fibrous and fibrous layers developed from lake remnants and stages of peat-forming vegetation that indicate major fluctuations in water level and accompanying changes in vegetation.

- 0 to 23 inches, tule-reed muck. The surface organic material, to a depth of 8 inches, is cultivated organic residue, grayish black in color, granular, friable, and more or less neutral in reaction. Between 8 and 23 inches below the present surface is rather dense heavy-textured dark grayish-brown tule peaty muck, firm and partly fibrous. This material contains black organic sediments and a variety of seeds from waterlilies and pond weeds.
- 23 to 38 inches, yellowish-brown matted poorly decomposed fibrous reed peat which is commonly referred to as "buckskin" peat. It is slightly acid in reaction. This layer represents, probably, a floating mat.
- 38 to 72 inches, grayish-brown tule peat, in part sedimentary fibrous. The material consists of varying quantities of rhizomes from reeds and organic sediments and contains seeds from a contemporary herbaceous and aquatic vegetation. At the lower level the material is more distinctly heavy textured and sedimentary fibrous.
- 72 to 96 inches, brown fibrous or matted-fibrous partly decomposed tule-reed peat. The material is mottled with black organic residue and maroon-colored fragments that appear to have been formed by herbaceous plants during high-water stages.
- 96 to 114 inches, yellowish-brown reed peat characteristic of a floating mat. The material is coherent, essentially well preserved, and porous. It grades rather abruptly into the layer below.
- 114 to 120 inches, grayish-brown structureless sedimentary peat which developed from plant communities that occupied open water. The material consists in part of transported plant remains, leafy fragments of pond weeds, and bits of fiber from floating mats of vegetation.
- The underlying mineral material is gray compact sticky clay.



A, Clamshell dredge excavating tule peat as a commercial product near Wintersburg, Calif. Rainfall is stored in the dugout area during the wet season. B, Type of dredge used in building levees and in excavating the larger channels between peat islands in the Sacramento-San Joaquin delta land.



A, Siphon located on the inside slope of a levee in the delta land of California. *B*, Flooding peat land and ditches with water siphoned from channels in the delta of San Joaquin and Sacramento Rivers.

An interesting feature in the cultural methods preparatory to irrigation is the network of so-called "spud ditches" (pl. 3, *A*) constructed each year by machine. They receive water for irrigation directly from pipe siphons or by pumps and floodgates. For some crops the water table is brought almost to the surface of the ground. Celery fields, for example, are frequently flooded before planting. Winter flooding also has been used to eradicate animal pests, but as a general rule the more radical remedy of burning off the topsoil (pl. 3, *B*) is used to destroy disease-producing organisms, weeds, and pests of various kinds. However, the cumulative effect of cultural burnings results not only in a rapid loss of surface material but also in a lowering of the peat land below water levels, which constitutes a serious hazard to the stability of levees in the delta land of California.

(11) SHERMAN PROFILE

At the western end of the delta peat land a profile was taken on Sherman Island, near the junction of the two rivers and about one-half mile west of Curtis Landing. The Sherman profile is characterized by a normal sequence of three layers and illustrates the development of peat profiles in deep-water basins. The area is under cultivation to asparagus. During floods it is occasionally inundated by breaks in the levee.

- 0 to 12 inches, tule-reed muck. The cultivated surface soil to a depth of 10 inches is gray or dark-gray well-decomposed granular loamy mellow tule-reed muck, containing an appreciable quantity of river sediments. It is underlain by a thin band of drab or buff silty clay mottled with plant remains and rusty-brown stains along root channels.
- 12 to 72 inches, yellowish-brown coarsely fibrous matted reed peat which is poorly decomposed and slightly acid in reaction (pH 6 to 6.5). This material contains small quantities of plant remains from tule and well-decomposed organic components. The content of organic sediments is noticeably higher in the middle part of the layer, and the deeper part is more fibrous, saturated with water, and contains hydrogen sulphide gas.
- 72 to 228 inches, brown or olive greenish-brown sedimentary-fibrous tule peat. The material is firm and contains a variety of seeds and a few rhizomes of reeds. At variable depths it has a somewhat fibrous character, suggestive of changes in the cover of an encroaching wet-marsh vegetation.
- 228 to 372 inches, dark-brown organic sediments. At the upper level the material is coarse textured, moderately dense, and contains transported bits of plant remains, leafy tissue from pond weeds, diatoms, together with charred organic material, and an admixture of clayey river sediment. At its lower level the layer is more or less stratified, heavier textured, and includes thin bands of gray sticky clay which contains fragments of roots and rhizomes.
- The underlying mineral material, to a depth of 33 feet below the present surface, is grayish-blue sticky clay containing a few fragments of plant remains that may have drifted downstream.

DISCUSSION

Although these three type profiles have considerable pedologic significance, they represent but a few of the members that might be designated as the delta series. Other type profiles, particularly in relation to undrained conditions and native vegetation, have been described elsewhere in connection with the principles and methods of classification of peat land (9).

The future need of water in the delta area might result in setting aside certain islands or bodies of peat land as storage reservoirs, even

though their value for water conservation may be limited to local requirements.

For the purpose of water storage, only such islands or peat areas should be considered as those that have profile features and physical characteristics of limited benefit to agricultural production, and that are now less profitable, owing to the presence of excessive amounts of salts, or whose levees cannot afford a reasonable degree of protection against winter floods in excess of the capacity of leveed channels. If such storage reservoirs are made along the principal water channels they should be of considerable consequence in the future.

In the delta area the surface organic soils or muck, developed from the decomposition and cultivation of the respective peat materials, are composed for the most part of gray-brown or gray-black granular or powdery organic residue, friable and loamy, more or less mixed with mineral matter. The organic material below the surface is, however, essentially different in character. Separated on the basis of the physical characteristics of peripheral peat layers, to depths ranging from 3 to 4 feet, the delta peat land may be differentiated as follows:

1. Areas of dark-brown or black sedimentary-fibrous tule peat and sedimentary peat. The organic material, which is essentially heavy textured and developed in standing water, consists mainly of fine sediments, jellylike or colloidal in character, and contains varying quantities of fibrous material, seeds, and plant remains from water-lilies, pond weeds, cattails, and other plants.

Material of this kind is frequently termed muck, or organic soil. However, it may not always represent a stage of soil development. This material seems to be predominantly sedimentary peat because of the character of the plant remains. It has not developed into muck or residue, as the layer is not sufficiently permeable to air and the action of micro-organisms, worms, and insects. It is moderately compact, heavy textured, and plastic, heavy in volume weight, and not readily aerated or penetrated by roots. It hardens on drying, cracks into fragments of varying dimensions, has a poorly developed drainage capacity, and is frequently inundated during rainy seasons. The difficulty of leaching out any salts that have accumulated or combined chemically with the organic sediments limit the use of this kind of peat. If storage reservoirs are made of areas of this kind, they would afford protection against losses of surface and ground waters.

2. Areas of brown or reddish-brown tule-reed peat which is distinguished from the material just described by the presence of yellow rhizomes of reeds that improve the permeability and water-absorbing capacity of the layer. In physical characteristics this material is intermediate between the comparatively heavy and impervious sedimentary or sedimentary-fibrous tule peat and the light porous reed peat described in the following paragraph. The material is low in plasticity and cohesion and readily allows drainage. Its absorptive capacity is high for nutrient bases in exchangeable or nearly available form. It is easy to cultivate, but the granular residue is subject to blowing when too dry, and to accompanying losses of nitrogen that accumulated during decomposition of the organic material.

3. Areas of yellowish-brown or reddish-brown coarsely fibrous or felty reed peat (buckskin peat) which is poorly decomposed; light in weight; permeable to water, salts, and air; of comparatively high water-storing capacity, owing to its open texture and buoyancy; but of low capillarity and hence subject to drought and to burning when ground-water levels are at depths of more than 3 feet below the surface. Cyclic storage of water and control of salinity are practicable in this type of peat land. A part of any flood water stored in the layer would seep into the underlying mineral substratum or into adjacent stream channels, thus affording, for a time, regulation of flow and materially reducing salinity and the incursion of salt water. The use of reed-peat areas as water reservoirs would conserve surface waters, replace the depleted underground storage, and furnish a source of water supply free from injurious salts for the more productive areas of tule-reed peat.

Losses of stored water are common to both cultivated peat areas and reservoirs. To the volume of water stored in reservoirs that will be lost by direct evaporation during the months when water is in demand must be added the losses from transpiration by plant communities that usually develop in open bodies of water in the form of herbaceous plants or different successions of aquatics, rushes, sedges, and cattail. Such water losses under natural conditions have been determined by the division of water resources of the State of California (3). However, further research should include data on percolation and on the volume of roots and rhizomes produced by the plants, and their influence in absorbing rainfall, holding back stream flow, and prolonging the time for percolation.

Profiles containing a comparatively large admixture of mineral material (more than 60 percent) have been separated in accordance with the usual concepts applied to peat land. It is important to observe that formation of peat has continued in most cases since the close of the glacial period. The development of organic soil and the process of its differentiation, however, have begun only recently with drainage and lowered water level. The deposits are constantly disturbed at the surface and altered by cultural operations and fluctuating water levels, which keep the profiles in a very young stage of soil formation.

PEAT LAND IN THE KLAMATH BASIN OF OREGON AND CALIFORNIA

The Klamath River watershed lies in northwestern California and south-central Oregon (34) (fig. 3). It has a drainage area of about 15,500 square miles. The upper part of the Klamath Basin consists mainly of a series of volcanic plateaus ranging in elevation from 4,000 to 5,000 feet above sea level. In general the basin is flat and is deficient in forest cover, but it contains large areas of tule marsh which are impounding water supplies, notably around Upper Klamath Lake. The lower part of the drainage basin lies almost entirely in California and practically all of it is mountainous and forested. The Soil Survey Division has mapped a portion of the plateau section including 384 acres of peat (30). More recent maps of various parts of the watershed have been published by the United States Geological Survey and by the United States Forest Service, in

connection with a study by the Forest Service of the power possibilities of Klamath River.

Klamath River rises in the plateau and meanders through flat marshy country to Upper Klamath Lake, into which empty several other streams that drain the northern part of the plateau area. The river then breaks over a lava reef and enters a rugged, winding canyon, cutting its course to the ocean through well-forested mountains of the Coast Range.

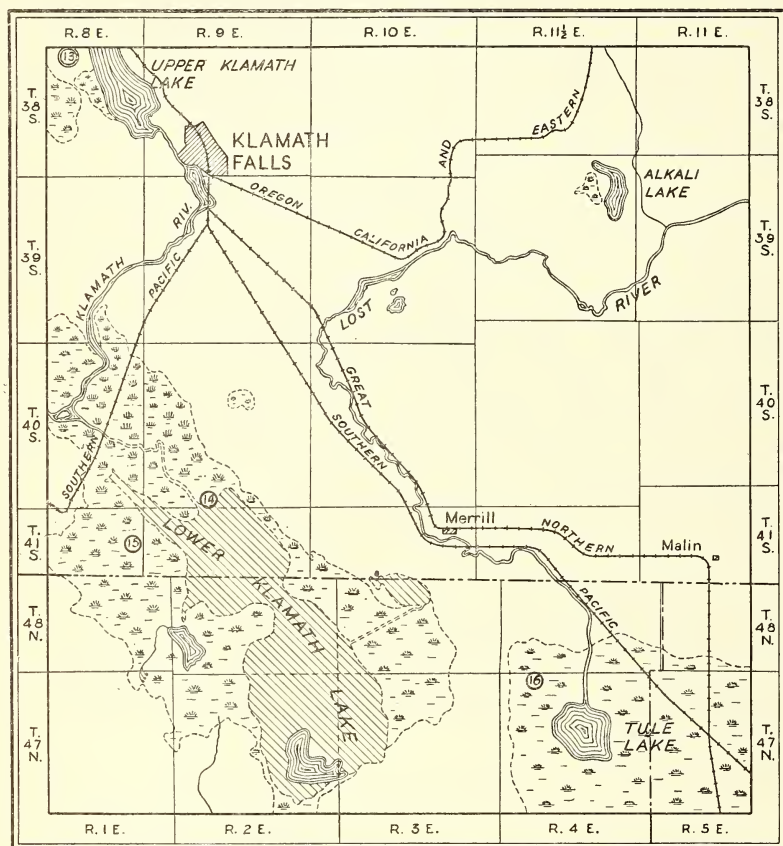


FIGURE 3.—Upper and Lower Klamath Lakes and Tule Lake in Oregon and California and location and numbers of profile soundings.

The mean annual rainfall in the drainage basin ranges from less than 15 inches on the upper plateau to about 100 inches on the summit of the Cascade Range. Most of the precipitation is distinctly seasonal, and occurs during the period from November to March. There seems to be a definite tendency for the occurrence of comparatively long wet periods followed by similarly long periods of deficient rainfall.

The run-off from the plateau is well maintained, owing in part to the fairly uniform flow of the spring-fed headwater streams, the extensive tule marshes, and the storage of water in Upper Klamath

Lake. In the lower part of the drainage basin the discharge becomes more seasonal. Floods on the river have been confined largely to overflow of the lowland near the mouth of the stream, and damage from floods is of small extent. The mean seasonal discharge is estimated at about 11,200,000 acre-feet.

In the development of the water resources of the Upper Klamath Basin, irrigation is of primary importance and is confined principally to that area. Considerable areas of peat land have been reclaimed under the control of the United States Bureau of Reclamation, including, in part, the bed of Lower Klamath Lake and the bed of former Tule Lake.

The probable expansion of irrigation, the amount of water that will be required, the possibility of "alkali" accumulation, and the need of conserving water now lost have been the subjects of study by various investigators.

PROFILES IN UPPER KLAMATH LAKE

Upper Klamath Lake is a body of water lying at an elevation of 4,143 feet above sea level. It has a surface area of 70,000 acres and a border of marshland of about 50,000 acres, half of which has been diked. The lake has a usable storage capacity of 450,000 acre-feet with a normal draw-down of 6 feet, or to an elevation of 4,137 feet above sea level. The annual run-off is estimated at 1,600,000 acre-feet. The demand for irrigation water from this lake varies from about 165,000 acre-feet during a normal year to more than 220,000 acre-feet during a year of low rainfall.

(12) ROCKY POINT PROFILE

Profile sections in the northern end of Upper Klamath Lake were observed in 1919 and again in 1927 at Rocky Point, with the cooperation of W. L. Powers. The area represents a part of the tule marsh bordering the lake. The water level is near the surface of the growing vegetation. Tule (*Scirpus occidentalis* (S. Wats.) Chase) cat-tail, various sedges, rushes, and wire grass, arrowhead (*Sagittaria* sp.), marshlocks (*Comarum palustre* L.), buck bean, and *Hypnum* mosses (chiefly *Aulacomnium palustre*, Schwaegr, *Drepanocladus* sp., and others) form the more conspicuous members of the plant community.

In relation to the native surface vegetation, the vertical cross section, designated as the Rocky Point profile, shows the following characteristic features:

0 to 3½ feet, tule peat, the topmost 2 inches of which are a mixture of dark-brown well-decomposed herbaceous residue and fibrous roots of the temporary plants of the marsh vegetation. The underlying material to a depth of 10 inches consists of light-brown pervious more or less felty-fibered tule and sedge peat, in which rhizomes are abundant and decomposition is not extensive. Below this the material is increasingly coarse fibered, matted, porous, and yellowish brown in color; it contains seeds of different plants and varying quantities of well-decomposed organic residue, embedded in the network of roots and rhizomes.

3½ to 5 feet, gray-brown sedimentary-fibrous tule and sedge peat, relatively dense and partly decomposed. The layer consists of fine-grained greenish organic sediments containing seeds of waterlily and thin bands of diatoms, giving it a more or less laminated structure; it suggests fluctuations in water level correlated with changes in the character of the peat-forming vegetation.

5 to 17 feet, brownish-gray diatomaceous sedimentary peat composed chiefly of siliceous shells of diatoms (various species of *Navicula*, *Fragilaria*, and others), silica spicules of fresh-water sponges, and a few shells of small mollusks. At the 6-foot level occurs a thin band of coarse white pumice. Below it, at variable depths, the layer contains soft gelatinous peat material derived from submerged herbaceous plants and free-floating microscopic life of lakes (plankton). It contains fragments of horsetail (*Equisetum* sp.), leafy material from tape grass and pond weeds, seeds, and wind-carried and water-transported charred particles. Diatoms are especially abundant at the greater depths.

Below the 17-foot level the material is increasingly siliceous (diatomaceous) and silty.

This type of profile is of extensive occurrence, particularly in the southern border of the marsh.

(13) WOCUS PROFILE

Soundings were made in 1929 and repeated recently in the Wocus marsh, a baylike tract of peat land about 9 miles northwest of Klamath Falls, Oreg. The area is drained by means of pumps which lift the excess water over levees. Alsike clover, following rye and colonial bent (*Agrostis tenuis*, Sibth) are under cultivation and irrigated by letting in water from the lake to the desired elevation.

The Wocus profile shows the following features:

Tule peat. The cultivated surface material consists of dark-brown or black granular mellow organic residue or tule muck to a depth of 8½ inches. It is fairly sharply demarked from brown fibrous moderately decomposed tule peat. This subsurface material grades into a thin mat of yellow-brown fibrous or felty-fibered tule-reed peat which is compacted through drainage and shrinkage and is neutral or slightly alkaline in reaction.

At a depth of 3 feet below the present surface the material is less fibrous. It contains seeds of waterhily and buck bean, flat rhizomes of cattail, and a comparatively large quantity of organic sediments, including sponge spicules and various species of diatoms. The material below this is yellowish brown or dark brown, is moderately firm, and represents a type of fibrous tule peat characteristic of mats floating on the surfaces of lakes.

At variable depths, but in most places between 5 and 6 feet, the material grades into greenish-brown or olive-green sedimentary peat which, at a depth ranging from about 6 to 12 feet below the present surface, is more or less stratified by the presence of thin, lensiform beds of *Hypnum* peat and coarse fragments of rhizomes from tule and scouring rushes. At greater depths occur well-preserved and greenish-colored leafy material from pond weeds and eelgrass, in addition to gelatinous sediments of algal and plankton derivation. The outstanding characteristic of this layer is the high content of siliceous shells of diatoms, most of which are light gray and become less stratified at greater depths.

PROFILES IN LOWER KLAMATH LAKE

Under natural conditions, Lower Klamath Lake had a water surface of about 30,000 acres, with an additional 58,000 acres of tule marsh bordering the margin of the lake (fig. 3). During flood seasons a considerable quantity of water overflowed annually from Klamath River into the lake. In 1917 this overflow was cut off by closing gates, and this procedure was accompanied by rapid drying of the marginal peat mat and oxidation of the ooze-like organic residue on the surface of the lake bed. Since that time rainfall and

drainage have not balanced with evaporation in the lake. Most of the former lake bed is now drying up. It is more seriously affected by drought than upland, and the residual material, being largely siliceous, does not provide the necessary plant nutrients for cultivated crops. In 1931 about 12,000 acres were still under cultivation and irrigated with water furnished by the Reclamation Service, but the results have not been successful. Evaporation has lowered the ground-water level considerably; the lake bed is accumulating alkali that combines with the disintegrating organic matter and is difficult to leach out. Climatic conditions, chiefly low temperatures, and short growing seasons are limiting the possible agriculture to grasses and hardy grains. Crop values are reported to average \$3.20 an acre.

(14) MERRILL PROFILE

Profile soundings of the marginal part of the former lake were made about 10 miles west of Merrill, Oreg. The area shows a rather striking demonstration of destruction. Over a wide expanse many acres have been denuded of vegetation, and the skeletons of cattle are strongly reminiscent of drought and shortage of feed. Fires have destroyed the cover of peat and the accompanying vegetation that was once a refuge for wildlife of high utility and an important protection against the inflow of salts and silt from upland soils. Reddish-colored ashes and uneven and irregular patches of dry peat remain, some of which range from 2 to 3 feet in width and from 1 to 5 feet in thickness. Injurious quantities of alkali tend to be concentrated on the adjoining lake-bed sediments. The area is now subject to wind erosion (pl. 3, *C*). Its surface soil is being blown off rapidly, and the agricultural use of many acres has been abandoned.

The vertical features of the Lower Klamath Lake peat, represented in the Merrill profile, were obtained in a remnant of the destroyed peat layer and are as follows:

- 0 to 25 inches, tule peat. The 14-inch surface material is reddish-brown coarsely fibrous coherent matted tule peat formed under conditions of a rising water level; the raw peat in its present stage is slightly decomposed, dry, tough, light in weight, and has many shrinkage cracks. Below it the material is brown fibrous tule peat less coarsely matted and less porous and penetrable. It contains soluble salts having an alkaline reaction. The evidence of salinity is visible on the exposed walls of the tule peat, which are coated with a gray incrustation near the level of the lake sediments.
- 25 to 32 inches, sedimentary-fibrous tule peat. The material is reddish brown with a rose-colored tint and consists of roots and rhizomes derived from rushes and tule. It contains an admixture of fine organic sediments including diatoms and a varying quantity of shells from mollusks. This layer is more or less impervious.
- 32 to 57 inches, sedimentary peat, consisting of grayish-brown or gray organic sediments. The material is laminated and firm and does not undergo marked shrinkage or changes as the result of drainage. Most of it consists essentially of siliceous shells of diatoms, together with varying quantities of organic matter. It contains a few remains of plant tissue from pond weeds, small shells of mollusks, and a few angular fragments of lava rock.

The thickness of the peat profile was not probed, but it increases with distance from the shore line. The sedimentary material is continuous with and similar in character to the diatomaceous organic sediments that make up the lake bed proper. Such profile records

as are available from previous studies from other sections represent more or less similar development. The areas produce at first good yields of crops, but, as the material is lacking in essential elements of fertility, yields soon decline when evaporation lowers the ground-water level and salts in injurious quantities begin to accumulate at the surface.

(15) DORRIS PROFILE

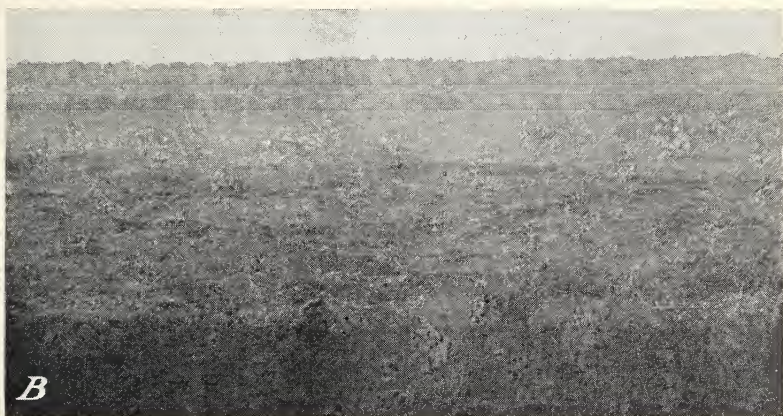
Northeast of Dorris, Calif., about 2 miles north of the California State line, a tract of peat land, under cultivation for the last few years, has yielded from 70 to 80 bushels of oats an acre without the application of fertilizers. The profile of a vertical cross section of a dug hole shows the following characteristic features:

- 0 to 15 inches, sedimentary muck. The 8-inch surface material consists of dark grayish-brown diatomaceous organic residue which is fine textured, granular, friable, and slightly acid in reaction. The material below this contains a moderate quantity of brown fibers derived from tule roots and rhizomes. In places the surface shows light-colored spots of incrustations, chiefly carbonate of lime. Probably some are magnesium and sodium carbonates.
- 15 to 19 inches, yellowish-brown diatomaceous organic sediments, well demarcated from the overlying cultivated material and containing an admixture of volcanic ash.
- 19 to 24 inches, blackish-brown fine-grained more or less colloidal organic sediments containing a large number of vertical roots. Water stands at the lower level, giving a neutral reaction.
- 24 to 36 inches, dark-gray diatomaceous sediments, faintly laminated and grading into light-gray siliceous material, chiefly shells of diatoms.

PROFILES IN TULE LAKE

The area occupied by Tule Lake formerly covered about 96,000 acres. Under natural conditions flood waters of Klamath River overflowed into Lost River and drained to Tule Lake which had no outlet. To reclaim the lake for farming, a diversion dam was built on Lost River and the water diverted to Klamath River. With the water supply thus cut off, about 18,000 acres of the lake bed have been placed under cultivation and irrigation. About 10,000 acres are retained permanently as a drainage sump, diked 5 feet above the lower end of the lake bed (i. e., to an elevation of 4,035 feet above sea level). The sump or reservoir is kept practically full of water during the irrigation season. Nearly 53,000 acres of undeveloped lake bed remain, of which possibly 45,000 acres may be leased from year to year and cropped. It is estimated that the fully reclaimed and developed lake-bed area will require 178,000 acre-feet of water a year, or about 1.5 to 2.5 acre-feet an acre. Ditches have been built leading from the drainage sump in various directions to carry water to the former lake shore and to leased land outside the developed project. Present plans contemplate the complete irrigation of 33,000 acres in the former lake bed and the partial irrigation of much of the remainder.

Profile soundings in the Tule Lake bed were made in the NW $\frac{1}{4}$ sec. 5, T. 47 N., R. 4 E., about 2 $\frac{1}{2}$ miles east from the shore line and 1 mile southwest of the road leading from the game refuge headquarters of the Bureau of Biological Survey. The area formerly had a dense and spreading cover of tule. On removal of the vegetation, the tract was cultivated and for the last few years its yield in barley is reported to range from 75 to 85 bushels an acre.



A, "Spud ditcher" excavating narrow ditches used for irrigation in the California delta land. B, Burning of cultivated peat land to eradicate plant diseases and animal pests. C, The effects of wind erosion, which carries away organic material from overdrained peat land in the Klamath section of Oregon.

(16) TULE LAKE PROFILE

Vertical cross sections, obtained by means of a dug hole, show the following characteristics of the Tule Lake profile:

0 to 12 inches, sedimentary muck. The upper 9 inches of the cultivated organic soil consist of dark-gray mellow diatomaceous material which is loamy in character. Below this is a brownish-gray diatomaceous organic sediment containing a few flattened rootstocks of waterlily, rhizomes, and rootlets of tule in an advanced state of decomposition, and possibly an admixture of clay. The underlying material is a thin band of white pumice which resembles coarse sand.

12 to 36 inches, very compact greenish-brown or olive-green organic sediments, largely diatomaceous and more or less banded.

36 to 72 inches, gray siliceous predominantly diatomaceous sediments. This material includes thin bands of coarse pumice from volcanic eruptions and varying quantities of clayey residue brought in, probably, by flood waters.

The material grades rather abruptly into a light-gray accumulation of siliceous remains of diatoms, which was not probed below a depth of 8 feet from the present surface.

DISCUSSION

Obviously the physical quality of the Klamath peat profiles, more than any other factor, determines differences in natural producing capacity and the future success of any agricultural practice. In the Klamath area, the presence of unusually large quantities of siliceous material, especially in the lake-bed profiles which are lacking in essential elements of mineral nutrients, marks the most significant distinction from the peat-land areas in the delta of the San Joaquin-Sacramento Rivers and that in the Willamette Valley in Oregon. The restoration of most of the peat land in the Klamath area as an aquatic resource might be of greater benefit than its reclamation as farming land.

The relationship between rainfall and run-off for the period 1904 to 1931 has been summarized by engineers of the United States Army and the Forest Service. The results, shown in table 1, indicate a continuous and fairly uniform falling off of the discharge from Upper Klamath Lake, mainly because of a constantly diminishing amount of rainfall during the entire period of recorded flows. The future water supply from this lake cannot be estimated with any degree of confidence as a measure of the water available for irrigation from that source.

TABLE 1.—*Total outflow from Upper Klamath Lake in relation to rainfall at Klamath Falls, Oreg.*¹

Season	Unregu- lated dis- charge	Precipi- tation at Klamath Falls	Season	Unregu- lated dis- charge	Precipi- tation at Klamath Falls	Season	Unregu- lated dis- charge	Precipi- tation at Klamath Falls
	<i>Acre-feet</i>	<i>Inches</i>		<i>Acre-feet</i>	<i>Inches</i>		<i>Acre-feet</i>	<i>Inches</i>
1904-05...	1,508,000	10.31	1913-14...	1,766,000	15.48	1922-23...	1,095,000	12.74
1905-06...	1,632,000	13.47	1914-15...	1,291,000	10.34	1923-24...	871,000	8.19
1906-07...	2,138,000	14.48	1915-16...	1,444,000	11.44	1924-25...	1,238,000	17.44
1907-08...	1,454,000	11.42	1916-17...	1,326,000	10.74	1925-26...	775,000	8.69
1908-09...	1,718,000	13.66	1917-18...	1,110,000	7.53	1926-27...	1,393,000	18.83
1909-10...	1,808,000	14.65	1918-19...	1,204,000	11.61	1927-28...	1,165,000	13.03
1910-11...	2,019,000	14.89	1919-20...	986,000	7.95	1928-29...	855,000	8.49
1911-12...	1,607,000	14.53	1920-21...	1,596,000	14.79	1929-30...	822,000	10.76
1912-13...	1,629,000	17.17	1921-22...	1,308,000	14.72	1930-31...	642,000	8.42

¹ House Document 181 (34).

There has been some discussion regarding reclamation of the Sycan marsh, at the head of Sycan River, and of the Klamath marsh. These marshes represent a level area of about 80,000 acres which receives the discharge of upper Williamson River. The future use of these marshes is uncertain. Klamath marsh has been considered a bird refuge and a possible water reservoir to supplement Upper Klamath Lake. The profiles of these marshes were not studied in detail.

The three-layered and one-layered series of profiles are of common occurrence throughout Lower Klamath Lake. Variations and marked departures do not express differences in stages of soil development or distinctions between type profiles.

Before its reclamation Lower Klamath Lake was the nesting place of migratory game birds and waterfowl. A movement is now in progress to restore the water level and the border of native vegetation to approximately the former natural conditions and to use the area as a bird refuge and regulating water reservoir. It is estimated that the proposed bird refuge would require 175,000 acre-feet of water annually. The water available for that purpose might come in part from Lost River Diversion Canal and in part from excess waters of Klamath River and Upper Klamath Lake.

WILLAMETTE VALLEY PEAT LAND

The Willamette drainage basin includes an area of about 11,200 square miles (33) in northwestern Oregon. It lies between the Cascade Mountain Range, with elevations ranging from 3,500 to 5,500 feet above sea level on the east, and the Coast Range on the west which does not exceed 1,500 feet average elevation. Willamette River and its principal tributaries have their source in the forest-covered mountains. This stream drains a flat troughlike alluvial-valley floor and has an outlet into Columbia River at tidewater level near Portland, Oreg. Two national forests are wholly within the watershed, as well as parts of other National and State reserves.

The average annual rainfall ranges from 40 inches over the greater part of the valley to 130 inches on the north of the Coast Range. In the Cascade Mountains much of the precipitation falls as snow and remains for a long time retained in natural storage and tending to maintain a well-sustained low-water stream flow during the dry season. The summer rainfall in the valley is light, and frequent recurrence of periods of drought make irrigation desirable to assure the growth of crops during the period from June to September. The growing season on the valley floor averages about 180 days, and the climate is semiarid.

The water requirement for the dry season is estimated at 500,000 acre-feet annually. A part of the supply is obtained by gravity diversion from the natural stream flow and a part by pumping from ground-water supplies. The mean annual discharge of Willamette River at Salem, Oreg., is about 22,500 second-feet. High-water stages in the river, with a crest height of about 20 feet above low-water level, ordinarily occur during the winter, and their duration varies from 5 to 20 days. Flood damages in the basin are in general small and are confined to bottom land along the main stream and some of its tributaries. Overflows do not occur during the crop

season, and the periodic silt-laden inundations are not regarded as detrimental.

The greater part of the peat land occupies low-lying depressions of the river bottom and the alluvial valley plain. One body of peat, however, occurs on the upland near the boundary of the watershed. The topographic features with respect to adjacent streams allow both drainage and irrigation. Maps and reports by the Soil Survey Division, in cooperation with the Oregon Agricultural Experiment Station, show the distribution of 5,928 acres of peat land in the Willamette Valley.

PROFILES IN LAKE LABISH

This area of peat land lies in Marion County, Oreg. (31), in the lower basin of Pudding River which is a winding and sluggish tributary flowing into Willamette River north of Salem, Oreg. Lake Labish appears to have been, in its original condition, a marshy lake with willow-bound margins tending to debar or slow down silt-laden floods and the run-off from heavy rains. The lake is about 9 miles long and nearly a quarter of a mile wide, and it is bordered in places by old shore lines from 15 to 25 feet above the present surface. The lake bed includes about 2,400 acres. It was drained in 1912 and is now irrigated in some places by pumping from drainage canals and by subirrigation. The principal crops are onions (1,300 acres), celery (500 acres), peppermint (200 acres), and, to a smaller extent, such truck vegetables as tomatoes and carrots, and the yields produced with the aid of mineral fertilizers are large. Other areas, known locally as "beaver-dam" peat land, occur near Woodburn and east of Hubbard in Marion County, and near Milwaukie and Clackamas in Clackamas County (19).

(17) LAKE LABISH PROFILE

Profile soundings were made at various times with the assistance of W. L. Powers, of Corvallis, Oreg. On a tract about 600 feet west of the road to Chemawa and approximately 4 miles north of Salem, the Lake Labish profile shows the following features:

- 0 to 15 inches, tule muck. To a depth of 8 inches, the surface material consists of dark-gray granular and friable organic residue having a somewhat high content of mineral matter, charred debris from surface fires, ashes, and moderate quantities of silt washed down from adjacent higher land. The underlying material is grayish black, compact in structure, and acid in reaction (pH 5.5). It breaks with conchoidal fracture into angular lumps and granules. In places it contains roots of plants and the casts and channels of earthworms.
- 15 to 72 inches, yellowish-brown fibrous or felty-fibered tule-sedge peat which is pervious and more or less mottled with black organic residue. At variable depths the layer contains rhizomes of reeds and is loose porous waterlogged reddish-brown or grayish-brown material. Its lower part is stratified, owing to the presence of *Hypnum* peat and organic sediments. The *Hypnum* peat is evidently the product of mats that floated under high-water conditions.
- 72 to 120 inches, dark-brown sedimentary-fibrous sedge peat which is less pervious than the material in the layer above. Near the upper level, there is a thin band of volcanic ash, coarse and pumicelike in character and neutral in reaction (pH 7), which sank into the water at a time of eruption when the lake was an open marsh. About 4 feet below this is a thin band of clay which had its origin, probably, in flood waters or wash from the bordering slopes.

120 to 228 inches, soft, more or less structureless, and sticky sedimentary peat which ranges in color from reddish brown to dark brown but is generally gray at the greater depths. The material contains varying quantities of fibered fragments, some of which are derived from marginal mats of peat. It also contains woody material from branches and trees, bits of rhizomes, roots, and leafy tissue, organic sediment, and mineral matter, chiefly silt and clay. Here and there at the lower level are logs of timber that appear to have been cut by beavers.

The underlying mineral substratum to a depth of 20 feet below the surface consists of gray or bluish-gray silty clay.

PROFILES IN WAPATO LAKE

There are about 3,200 acres of peat land in the drainage basin of Yamhill and Tualatin Rivers. They occupy valleylike depressions in which flood waters from the rivers may stand several feet deep during the winter season. The streams are minor tributaries of Willamette River and rise on the eastern slope of the Coast Range. They have a slight fall in their lower reaches as well as a small summer flow. In a number of places, oxbow lakes or bayous, representing former stream channels, have accumulated several layers of peat by the developmental sequence of plant communities. With the exception of Wapato Lake, most of the peat areas are small, and the popular name of beaver-dam peat land is applied to nearly all of them. It is generally believed that beavers raised ground-water levels, aided the spread of wet marshes, and thus increased the acreage of peat land by damming up creeks and streams.

Wapato Lake lies between Washington (39) and Yamhill Counties (18), Oreg. It has been drained by the construction of large open ditches and by the installation of pumps at the lower end of the valley, but in places it is still too wet for cultivation. The crops grown with the use of mineral fertilizers are cabbage, onions, potatoes, and small grains. Tracts in which drainage is poor and water stands within a few inches of the surface are used for grasses and hay.

(18) WAPATO LAKE PROFILE

A record of soundings in the part of this area that lies in Yamhill County shows the following features:

- 0 to 10 inches, sedimentary muck. The cultivated surface material consists of dark-gray granular organic residue which is silty from an admixture of mineral overwash. It contains only a moderate quantity of silt at the lower level and tends to break into irregular small angular granules.
- 10 to 68 inches, dark grayish-brown sedimentary peat containing flattened rootstocks of water lily, largely decomposed soft-tissued material from water vegetation, together with siliceous remains of diatoms, sponge spicules, and occasionally the rhizomes and roots of rushes.
- 72 inches +, olive-green finely divided peat material containing well-preserved leafy tissues derived from pond weeds and tape grass, small woody fragments (probably beaver-cut sticks), and black plant remains from horsetail ferns.

This material grades into the underlying mineral substratum which, at a depth of 11 feet below the surface, consists of compact gray sticky clay.

PROFILES IN THE TUALATIN FLATS

Northeast of Wapato Lake is an area of peat not far from Sherwood, in Washington County, Oreg. It lies about a quarter of a mile east of the highway to Tualatin and represents a depression in a former stream channel of Tualatin River.

(19) SHERWOOD PROFILE

The Sherwood peat profile shows the following features:

- 0 to 24 inches, sedimentary-fibrous muck. The surface material consists of dark-gray or grayish-black granular organic residue which is cultivated to a depth of 10 inches. It is silty from variable quantities of an overwash of mineral soil brought in by water from the adjoining higher land. Between depths of 10 and 24 inches the material consists of sedimentary-fibrous peat which is moderately firm and contains brown roots and rhizomes from sedges embedded in large quantities of fine-textured organic sediments.
- 24 to 168 inches, reddish-brown or yellowish-brown fibrous reed and sedge peat which is more or less felty, matted, and pervious. The material includes seeds of various kinds and small woody fragments. A faint odor of hydrogen sulphide is noticeable in the waterlogged part of the layer, about 10 feet below the surface. Between depths of 12 and 14 feet the material is brown or yellowish-brown fibrous *Hypnum* peat which is well preserved and contains a small admixture of diatomaceous sediments.
- 168 to 240 inches, olive-green organic sediments, which are more or less colloidal. This layer contains leafy fragments of tape grass and pond weeds and, at the lower level, an organic ooze formed from free-floating microscopic plankton including various species of diatoms. This material grades into clayey sediments and thence into the underlying sticky clay.

Flood waters carrying silt and slope wash from adjacent higher land are transporting mineral sediments to several of the peat areas, and their marginal parts have undergone considerable modification. The percentage of mineral material on the surface of such deposits is high, and some of the former wooded marshes are now included with the mineral soils.

PROFILES IN THE NOTI SPHAGNUM BOG

Near the western boundary of the Willamette River watershed, in the Coast Range, the annual precipitation varies between 50 and 130 inches a year. The Noti sphagnum bog is a variation which developed normally under local conditions but later assumed a form correlated with the higher rainfall. The deposit is situated east of Noti, in Lane County, Oreg., (5) within rough mountainous land at an elevation of more than 1,000 feet above sea level. An area of about 30 or more acres is located in the NW $\frac{1}{4}$ sec. 19, T. 17 S., R. 6 W., Willamette meridian, and is partly drained by a creek tributary to Long Tom River.

The cover of vegetation is similar to that of other sphagnum bogs that occur in northwestern Washington. The more common heath shrubs are Labrador-tea (*Ledum groenlandicum* Oeder) and laurel (*Kalmia glauca* Ait), rooted in moss peat. Several species of sphagnum are present, notably *Sphagnum fuscum* (Scimp.) Klinggr. which forms hummocks, from 10 to 14 inches in height, around the bases of heath shrubs. Other members of the plant community are the cranberry (*Oxycoccus oxycoccus* (L.) McM.), round-leaved sundew (*Drosera rotundifolia* L.), various prostrate herbaceous plants, and cotton grass (*Eriophorum vaginatum* L., *E. chamissonis* C. A. Mey). On the margin are stunted conifers, among them fir and cedar, indicating a forest succession in an initial stage. The natural drainage channel is bordered by willows, salal (*Gaultheria shallon* Pursh.), cascara (*Rhamnus purshiana* DC.),

Spiraea, and sweetgale (*Myrica gale* L.). From parts of the bog, the moss peat has been removed for use as packing material, and it is shipped in bales to California.

(20) NOTI PROFILE

In relation to the native surface vegetation, the profile soundings show changes which may be summarized as follows:

- 0 to 2½ feet, sphagnum peat. The sphagnum peat, which forms a part of the surface layer of the entire bog, ranges in thickness from 1½ to 2½ feet. It is light yellow brown, spongy, fibrous, poorly decomposed, strongly acid (pH 4), and intermixed with thin roots and small woody root sprouts of heaths. The lower part of the layer is reddish brown, is slightly more advanced in degree of decomposition, and contains an admixture of sedge rhizomes.
- 2½ to 4½ feet, sedge peat. Dark-brown or dark grayish-brown sedge peat which is moderately fibrous and matted, due to the presence of culms and rhizomes. The material is partly decomposed, contains seeds of various kinds and colors from herbaceous plants, such as buck bean and cowberry, and to a limited extent organic sediments, indicating that the layer is the product of a wet marsh.
- 4½ to 6 feet, sedimentary peat. Dark greenish-brown or grayish-brown sedimentary peat which is more or less colloidal and is diatomaceous at the lower level. Some of the material consists of fragments of rhizomes, pond weeds, gelatinous residue probably of algal origin, diatoms, and residue that was brought in by wind and water. In open ditches the material of this layer becomes hard and flaky when dry.

The record of this profile is consistent with the historical succession of the vegetation and the sequence of development seen in sphagnum bogs of northern areas. Ecologically it is to be correlated with a climate characterized by cool temperatures, abundant moisture, and a short growing season. During the first stages of development, organic sediments accumulated in open water that was well supplied with mineral salts. In the second stage, a quaking mat, chiefly the result of sedges, produced the layer of fibrous peat while there was still a remnant of open water. During a comparatively recent period, mosses encroached on the marsh vegetation and formed a layer of strongly acid moss peat—a result of altered nutrient conditions. Somewhat later the heath shrubs invaded, and only recently forest trees began to migrate into the firmer and more decomposed margins of the bog. The inevitable movement of vegetation is toward a swamp forest through disturbances in drainage channels that flow through the area, cutting into the layers of peat and lowering the water level.

DISCUSSION

As a general rule the morphological features of the profile sections obtained show clearly that the development of peat areas proceeds differently in different parts of the Pacific coast section. It is obvious that during early stages a variety of local conditions, such as land relief and ground-water level, are most important in determining plant successions and the sequence of peat layers. The general climate influences the later stages, particularly the tendency of vegetation to cover land surfaces and depressions with a plant community that absorbs precipitation and leads to the formation of a raised central peat area and to acid conditions wherever there is high rainfall.

PEAT LAND ALONG THE LOWER COLUMBIA RIVER IN OREGON

Along the lower Columbia River, between Willamette River Valley on the east and the coast section on the west, lies a broad smooth lowland which constitutes part of the delta of Columbia River. It occupies a position ranging from tide level to 20 feet above the mean water level of Columbia River. Until recently a very large part of the land was flooded during periods of high water in the river.

The bottom land of Columbia River has a rather wide range in climatic conditions. In the eastern section rainfall and temperature conditions are comparable with those in Willamette Valley. In the western section the rainfall increases from 45 to 75 inches, near the outlet into the Pacific Ocean, and is more typical of the Coast Range. Most of the precipitation occurs during the wet season, from October to March, coming in slow rains known locally as "Oregon mists." Fogs are common in the winter, but very little precipitation takes place in the summer. The growing period is, therefore, warm and prevailingly dry, and the prolonged dry season naturally entails drought, thereby causing injury to crops.

In Columbia County, Oreg., the distribution and location of about 6,720 acres of peat land have been mapped, and their agricultural treatment and crop yields are discussed in a report of the Soil Survey Division (16). In Clatsop County, Oreg., the acreage and proportionate distribution of peat land is not yet known. Fairly large areas along Columbia River are provided with a network of drains and have been protected from overflows by dikes. The water table is lowered by pumping. Practically all kinds of truck crops can be grown, with satisfactory yields, and the land produces natural pastures as well as hay grasses, Ladino and alsike clovers, millet, mint, and potatoes. Some of the peat land is still uncultivated and comparatively inaccessible. Sloughs supporting willows and a mixed growth of reeds, sedges, rushes, cattail, and waterlily are scattered throughout the entire district. There are also areas of peat land having an overwash of mineral material similar to that of the Sauvie soils.

(21) QUINCY PROFILE

Included in the diked acreage of the Beaver drainage district is a large area of peat land in Columbia County. Vertical probings were made about 1 mile northwest of the Quincy railway station, on a road leading to Columbia River. The profile features are as follows:

- 0 to 15 inches, sedge muck. The 5½-inch surface material consists of grayish-brown silty or clayey organic residue. It is permeated by numerous roots of Colonial bent and overlies dark-brown or grayish dark-brown sedge peat, which is moderately decomposed, somewhat silty, firm, faintly laminated in structure, and contains flattened rhizomes of tule and rushes. At the lower level the material includes a thin band of clay that was laid down by unusual floods over fine-fibered sedge peat about 4 inches thick.
- 15 to 90 inches, grayish-brown or grayish-black sedimentary-fibrous cattail peat which is dense, sticky, and more or less admixed with mineral sediments. The material consists largely of bits of tissue from various herbaceous plants, together with some well-preserved rhizomes of reeds, sedges, and horsetail ferns, embedded in organic sediments. The plant remains indicate a growth of aquatic and submerged vegetation which may well be correlated with high water and floods, carrying mineral

material. A faint odor of hydrogen sulphide is noticeable, and marsh gas escapes from levels of more fibrous and porous peat.

90 to 108 inches, grayish-brown sedimentary peat, mottled with black plant remains from horsetail (*Equisetum* sp.) and containing silt and particles of mica.

The mineral substratum consists of dark-gray fine sand containing well-decomposed organic matter; it grades into gray fine sand.

In some sections of the area, mainly on islands or near the river, are some shallow bodies of peat land. The organic material at the surface consists usually of grayish-brown or dark gray-brown, moderately decomposed, partly fibrous sedge peat, ranging from 15 to 35 inches in thickness. On account of the annual rise in the river, the material contains varying quantities of mineral sediment from overflows. The subsurface material in this layer is rather heavy textured. It is not sufficiently permeable to air and micro-organisms to develop into muck and fine-textured organic residue or into stages of mineralized organic soils. The underlying mineral material consists of sandy or silty clay and it contains more or less well-defined root channels having rusty stains and bluish tints.

(22) CLATSKANIE PROFILE

In western sections of the peat area the profile is unlike the typical Quincy profile, differing from it in depth and in character of parent material. About 2½ miles northwest of Clatskanie, Oreg., in the Magruder drainage district, profile soundings were made north of the highway in an area that had been formerly under cultivation, but has now grown up to reed canary grass, bentgrass, and tussocky rushes. In relation to the surface vegetation the vertical cross section shows the following characteristics:

0 to 37 inches, sedge muck. In the upper one-half to 1½ inches, the material is granular silty organic residue, embedded in a dense network of roots of the growing vegetation. Below this, to a depth of 8½ inches, is dark grayish-brown well-decomposed sedge muck which breaks readily into crumbly particles and favors the growth of plant roots. It includes a thin band of gray silty clay stained rusty red and penetrated by roots. Between depths of 8 and 37 inches the material consists of dark-brown partly fibrous peat derived from cattail and sedges. It is more or less heavy textured, thereby restricting drainage. It has an odor of hydrogen sulphide, contains methane gas, and at the lower level is grayish brown and recognizably stratified by an admixture of mineral sediments.

37 to 240 inches, brown fine-textured silty sedimentary peat grading into gray silty and clayey organic material. At variable depths the layer is more or less mottled with black organic sediments and stratified or banded by stream-borne mineral matter brought in by flood waters. Toward the bottom, the organic sediments embedded in clay are layered and consist mainly of black well-preserved sheaths, branches, rhizomes, and roots of horsetail.

The underlying mineral substratum was not reached at a depth of 20 feet below the present surface. Columbia River at this point has a 30-foot channel to the Pacific Ocean.

DISCUSSION

The most evident ecological generalization to be drawn from these profiles is that the vegetation accompanying the retreat of the glaciers consisted mainly of horsetail fern and must have been comparatively uniform and simple in botanical composition. During the period which followed postglacial conditions, the changes in

plant successions were not of the order of magnitude that occurred later and are recorded, for example, in the upper two-thirds of the profile.

For crop production irrigation is desirable during the dry season. This could be accomplished on the bottom land of the Oregon side of the river if proper storage of the high-water flows were provided. The mild winter climate and the abundant though not well-distributed water supply (13) of the area seem to offer possibilities of future intensive horticultural development, such as has been successfully carried out on the Willamette Valley peat land. For this reason attention should be paid to the finer distinctions of peat materials and the modifying conditions associated with productivity and likely to be of agricultural significance, rather than those on which the broader morphological differences are based.

PEAT LAND IN THE NORTHERN PACIFIC COAST SECTION

The northern Pacific coast section consists, in general, of a narrow shelf or plain of uniform, level topography, bordered on the west by ranges of hills. Many of the side slopes are steep and abrupt, and some are terraced. The hilly upland areas have an elevation ranging from 200 to 700 feet above sea level, and farther to the east assume a more rugged aspect, with elevations of more than 1,500 feet. The areas are dissected by small valleys marking the location of alluvial plains, sloughs, and irregular streams that comprise the major surface-water supply of the region.

The greater part of the coastal plain consists of porous sandy soils and soils having a silty or clayey texture. In places, bordering the ocean and approximately parallel to the coast, are large areas of wind-blown sand and drifting sand dunes. Here peat land is associated with present or former depressions between the sand dunes, within areas of alluvial soils along the streams, and on the hills and uplands, that are composed of sandstone, shales, and to less extent volcanic rock.

The climate of that part of the Northwest is reported to be equable—clear cool summers alternating with comparatively long, rainy seasons during the winter. The prevailing westerly winds from the Pacific Ocean produce a fairly high rainfall, partly the result of the coastal mountain ranges acting as an important barrier. On the humid slope of the mountains precipitation ranges from approximately 50 inches north of San Francisco Bay to 125 inches on the coast of Washington.

The water problems of this section are fairly well defined by natural conditions. The comparatively heavy rainfall makes flood control and erosion highly important. The annual run-off in the southern part of this section varies generally from 3.7 cubic feet of water per second per square mile to more than 7.4 cubic feet in the northern part of the Coast Range. Although much of the section has been experiencing a period of deficient rainfall during the last few years, there is reason to believe that this period of low precipitation may be succeeded by an increased rainfall. However, the conservation of water by storage of seasonal run-off in periods of wet years is not, as yet, considered necessary as a protective measure.

(23) FORT BRAGG PROFILE

The Fort Bragg peat area in Mendocino County, Calif., lies about 125 miles north of San Francisco and departs little, if any, from general conditions in the northern Pacific coast section. It is on the upland about 300 feet above sea level in the NE $\frac{1}{4}$ sec. 17, T. 18 N., R. 17 W., about 2 miles east of Fort Bragg on the highway to Willits. The deposit represents a sphagnum bog about three-fourths of a mile long and from 350 to 550 feet wide. It is the headwater of a small creek flowing into Noyo River, and thence into the ocean at Fort Bragg. The bog is surrounded by second-growth forest that consists mainly of pine, fir, hemlock, and cedar. The more remote eastern part of the upland is covered with redwood forest.

The bog itself supports a scrubby growth of trees, largely *Pinus contorta* Loudon, *P. muricata* D. Don, and *Cupressus pygmaea* (Lemmon) Sargent. The shrubby undergrowth is mainly *Ledum columbianum*, a scattering of *Myrica californica*, a few laurel and azalea, and a low growth of salal. There is a wet depressed margin, owing to decomposition of the organic material and seepage from higher land. *Spiraea*, together with other shrubs, is common in this transitional belt. In the more open central part of the bog there are several sedges and various species of sphagnum, among them *S. fuscum*, forming hummocks in the protection given by *Ledum*. The herbaceous ground cover consists of round-leaved sundew, cranberry, orchids, gentian, and others. In general the aspect of the bog stage of vegetation is very much like that of the bogs of Oregon and Washington. Information regarding this bog has been published by Rigg (29). The surface growth of sphagnum is now being collected by local owners and shipped in bales to San Francisco for use by nurserymen and others in packing fruit and vegetables.

Vertical cross sections of the peat area show the following features:

- 0 to 8 inches, reddish-brown poorly decomposed spongy-fibrous and strongly acid moss peat. In places this layer is 18 inches thick but is intermixed with rhizomes of sedges and underground stems of shrubby heaths.
- 8 to 42 inches, grayish-brown fibrous sedge peat having a matted structure characteristic of felty peat. It is partly disintegrated. This layer contains woody material, mainly from roots of shrubs and trees, and at the lower level it is interbedded with silt and sand.
- 42 to 56 inches, the underlying mineral substratum of sandy clay, characterized by an abundance of roots and rhizomes from sedges and by rusty stains. This material grades into light-gray sand.

In Coos County, Oreg., the areas of peat mapped by the Soil Survey Division (26) include an extensive marsh lying inland along Coquille River and small sphagnum bogs, some of which occur within the narrow belt of sand dunes along the ocean and others on the rougher and more elevated upland.

(24) BANDON PROFILE

In the upland section, about 3 $\frac{1}{2}$ miles southeast of Bandon, Oreg., are several small sphagnum bogs which have been cleared for the culture of cranberries. These areas represent shallow depressions that form a part of the rugged topography of the upland. They are associated with a forest in which second-growth fir, cedar, hem-

lock, and other trees are generally conspicuous. The list of plants characteristic of surface conditions on the undisturbed bogs is practically the same as on the bog examined near Fort Bragg, Calif.

One or more of the reclaimed bogs are reported as being free from weeds and disease organisms, and as producing yields frequently as high as 1,100 bushels of cranberries an acre. The clearing of brush has removed the original plant cover. Labrador-tea is among the last plants to disappear after ditches and dikes are constructed. In most places the leveling and sanding of the peat area has left little of the surface layer of moss peat.

In general the profiles show the following characteristics:

- 4 to 6 inches, a cover of sand, more or less banded, medium to coarse in texture, and bound together by the growth of cranberry roots and runners.
- A 10-inch layer of brown fibrous strongly acid sphagnum peat in varying degrees of decomposition. The material contains a few charred woody fragments in places where the bog stage supported a scattered stand of coniferous trees.
- An 8- to 20-inch layer of fibrous or felty-fibered reddish-brown or wine-red partly decomposed sedge peat. An admixture of organic sediments is present in many places, some of which represent remains from water-lily, buck bean, and other herbaceous plants of a wet-marsh stage.
- Sedimentary peat, variable in thickness and consisting of black, fine-textured organic sediments which are more or less pasty. The material is firm and hard when dry, indicating that this layer was produced in a shallow body of water by aquatic-plant communities during the early or first stage of profile development.
- In most places the underlying mineral material consists of dark-gray clay mottled and stained in the contacting horizon between the overlying organic sediments and the gray clay at greater depths. In other places the mineral substratum is residual sand or native rock.

(25) COOS PROFILE

In the narrow belt lying at a low elevation and extending from Coos Bay beyond Hauser are several tracts of peat land on which selected varieties of cranberry are growing. Some of the peat areas are near the coast in the sand-dune section, and others occupy depressions originating from minor streams that had their outlets obstructed by shifting dunes. Most of them were at the stage of successional development, during which the surface is covered almost entirely with sphagnum, heath shrubs (*Ledum columbianum*, *Kalmia portfolia* Wang.), and related plants comprising a bog vegetation.

Scalping of the surface vegetation has been deep enough to remove the larger part of the spongy-fibrous moss peat. In most places an 8-inch cover of gray sand rests on brown or reddish-brown fibrous sedge peat which is poorly decomposed to a depth of about 12 inches. Here and there thin bands of sphagnum peat are present in this layer, with other plant remains. The material in this layer grades into a sandy organic sediment containing black residue, rust-red stains of an iron salt, and a small quantity of moderately decomposed rhizomes and roots from sedges.

The underlying sand is less stained. There is no particular evidence of salinity, although the water standing in open ditches gives a neutral reaction. The peat material in a few areas is giving off an odor of hydrogen sulphide. This peat is reported to be unsatisfactory for the successful growth of cranberries, and it is brackish at times from the influence of high tides.

(26) HAUSER PROFILE

About one-third of a mile east of Hauser, Oreg., is an area of peat land which has been partly reclaimed by the installation of dikes and levees. The original vegetation consisted of cattail, sedges, and rushes, together with clumps of alder and willow. The cover was similar to the plant community still present on parts of the marsh along Coquille River. Attention has been attracted to this area because here the first attempt at supplying seed on a commercial scale, by the cultivation of Colonial bent, was made.

The recognizable distinctions in the profile section indicate the following features:

- 0 to 11 inches, sedge peat. The 3-inch surface material consists of a yellowish-brown finely matted or felty network of roots, largely from the contemporary growth of bentgrass. The material below is essentially brown or dark-brown partly decomposed more or less firm and faintly laminated sedge peat, containing a few woody fragments from alder and willow and demarked from the underlying layer of peat by a distinct change in color.
- 11 to 23 inches, sedimentary-fibrous peat, the upper part of which consists of a thin band of gray diatomaceous material about 1 inch thick. This grades sharply into dark grayish-brown sedimentary-fibrous peat. The organic sediments contain brown roots, blackened plant remains derived from waterlily and cattail, and a small quantity of silty clay.
- 23 to 28 inches, a band of gray clay washed in from the marginal upland. It contains small root channels stained rusty red and is underlain by an admixture of brown fibrous plant remains from sedges.
- The underlying mineral substratum consists of gray silty clay over sand, which is less stained and mottled at greater depths from the surface.

The larger area of marsh along the river west of Coquille, Oreg., shows a profile strikingly similar in appearance. Variations in texture are frequent, depending mainly on the relative proportions of silt and sand brought in by flood waters.

North of Coos County, Oreg., the Coast Range is characterized by very broken topography, and areas of peat are comparatively uncommon, even in districts where atmospheric conditions are favorable for the development of sphagnum bogs. The most important areas examined, representing the effect of a comparatively cool and humid oceanic climate, occur along the coast in Tillamook and Clatsop Counties, Oreg., and in Pacific County, Wash. The bogs are situated close to the ocean and near sea level, and their surface rises perceptibly from the margin to the center.

Nearly all the bogs are bordered in part by a moderate slope supporting a tree growth or a forest dominated by fir, hemlock, cedar, and pine, together with an undergrowth of shrubs, among them salal. The horizontal successional relationships in many areas include a transitional shallow marginal ditch, or "lagg", but as a rule the forested border is practically on a level with the heath-covered border. The marginal depression usually supports thickets of *Spiraea* with sweetgale. It consists of more or less settled decomposed organic material and is not always wet from seepage water.

The central parts of the bog are more or less dotted with stunted trees, mostly shore pine (*Pinus contorta*), some hemlock, and cedar. Numerous hummocks of sphagnum give the surface a comparatively smooth appearance, but depressions between them are not uncommon. Many of the hummocks are marked by a dense growth of cranberry

vines, sundew, and other small plants, and the wet hollows or pools of water may contain waterlily, or western skunkcabbage (*Lysichiton* sp.), marshlocks, buck bean, and sedges from a previous marsh stage. In moist depressions the interesting and characteristic cotton grass grows, also beaked rush (*Scheuchzeria palustris* L.), liverwort, and lichens, such as reindeer moss (*Cladonia* sp.). In addition to Labrador-tea, which is abundant in most places, the heath-shrub community contains laurel, blueberries, dwarf birch (*Betula glandulosa* Michaux), and a few *Andromeda polifolia* L. and *Empetrum nigrum* L. Fires, which occur at times of drought, usually kill or severely injure trees and shrubs, but only during long dry periods or excessive drainage does burning affect the ground cover.

(27) TILLAMOOK PROFILE

A sphagnum bog about 3 miles from Sandlake, Oreg., in sec. 20, T. 3 S., R. 10 W., comprises from 80 to 100 acres. A part of it is utilized for the commercial production of moss peat as poultry litter, stable bedding, and soil conditioner. Like most of the sphagnum bogs the surface is covered with moss peat of varying thickness. Marginal areas have been burned over and are drained by large open ditches. The part which has been left undisturbed is a tract of possibly 100 acres. It supports a bog vegetation that appears also to have been relatively unaffected by fires.

Soundings in the undisturbed and more centrally located parts of the bog illustrate the following profile features:

0 to 36 inches, moss peat. The surface layer, including hummocks of moss peat, ranges in thickness from 8 to 36 inches. It consists of light, straw-yellow, spongy-fibrous moss peat, which is well preserved, strongly acid in reaction (pH 4), and interlaced with roots of cranberry vines and heath shrubs. This material grades into brown or yellowish-brown firmer moss peat, derived predominantly from *Sphagnum fuscum*. There are traces of bands or lensiform accumulations of moss peat, that are typical of shallow pools of water in which carpets of *S. cuspidatum* Ehrh. and other mosses were at one time abundant. Stumps and roots of conifers are also present at the lower level.

36 to 104 inches, grayish-brown partly decomposed matted or felty-fibrous sedge peat. The material is more or less layered, moderately acid in reaction (pH 5), and contains rootstocks of herbaceous plants. It is underlain by a flocculent mass of brown or reddish-brown material, mainly fragments of roots and rhizomes, suspended in water and thickening with depth. The water pocket is, probably, the remnant of a secondary pond that was overgrown by a quaking mat.

104 to 132 inches, sedimentary-fibrous sedge peat. This is a grayish-brown mixture of fibrous material and organic sediments, moderately decomposed. The layer ranges from light to denser material and contains a comparatively high proportion of ooze-like organic residue at greater depths.

The mineral substratum consists of gray or bluish-gray sand containing particles of mica. It is neutral in reaction (pH 7).

Nearer the outer margin, where the surficial layer of moss peat had been removed, the exposed layer of sedge peat is about 60 inches thick. It ranges in color from gray brown to reddish brown, is coarse fibered near the upper level, contains roots of trees and shrubs, some of which have been cut by beavers, at a level ranging from 12 to 20 inches below the present surface, and it also has a small admixture of organic sediments near the bottom. The material overlies bluish-gray micaceous sand.

In Clatsop County, Oreg., the coast is bordered by drifting sand which was thrown up by the waves and carried inland by winds. The irregular ridges and dunes of sand, in general, have their largest diameter approximately parallel to the coast, and in many places they enclose peat land. Some of the deposits are sphagnum bogs, others are marshes, and a few are well covered with timber, showing that the rate of peat formation depends partly on the depth of the depression but largely on the character of the natural stages of vegetation succeeding one another to an ecologic stability.

In the vicinity of Seaside, Oreg., the profile features of unreclaimed sphagnum bogs are more or less similar to the Tillamook profile, and scalped areas of peat, utilized for the commercial growth of cranberries generally resemble the Coos profile. The marshy tracts illustrate, more commonly, features of the Hauser profile.

(28) CLATSOP PROFILE

In places where trees invaded marshy tracts, the original stand consisted of rather large conifers and related shrubs. Over practically the whole tract were at one time pines, to a less extent hemlock, and still more rarely cedar. In addition to these were thickets of willow, alder (*Alnus oregona*, Nutt.) and crab apple (*Pyrus diversifolia* Bongard). Thickets of *Spiraea douglasii*, Hook, and other shrubs occupied most of the wetter places or formed the characteristic fringe along small streams. Common constituents in the undergrowth were elderberry (*Sambucus callicarpa*, Greene), cascara, salmonberry (*Rubus spectabilis*, Pursh.), dogwood (*Cornus occidentalis* (Torr and Gray) Coville), vine maple (*Acer circinatum*, Pursh.), western skunkcabbage, and various ferns.

The results of test soundings indicate the following relations between the natural cover of vegetation and the peat profile:

0 to 18 inches, woody peat. The 6- to 8-inch surface material consists of very dark brown granular woody residue rather well advanced in degree of decomposition. The material below is less decomposed, contains coarse and lumpy woody fragments from roots and decaying timber, and has a somewhat larger content of reddish-brown material derived from a litter of needles, cones, twigs, and herbaceous components.

18 to 60 inches, dark-brown moderately decomposed and partly fibrous sedge and reed peat containing an appreciable amount of granular residue at the upper level. The material below this is distinctly matted or felty fibered and yellowish brown. In the lower part of the layer there is a slight admixture of organic sediments, suggestive of material formed in standing water.

The underlying substratum, which occurs at variable depths, is sand containing, in most places, black organic residue and roots. This material grades into dark-gray or gray sand which becomes less stained with depth.

(29) LONG BEACH PROFILE

On Long Beach Peninsula, in Pacific County, Wash., are about 2,000 or more acres of sphagnum bogs. An increasing proportion of this peat land is being cleared and planted to cultivated varieties of cranberry. Of the unreclaimed bogs, a large acreage borders narrow lakes between sand dunes that parallel the coast. A study of these bogs was made with the cooperation of D. J. Crowley, who is in charge of cranberry investigations at the Washington Agricultural Experiment Station. The present natural cover of vegetation and

its general relation to peat profiles differ somewhat from these features in other coastal sphagnum bogs. In their younger stages these bogs are characterized by a floating mat that fringes the open water of lakes and ponds. The formation of floating mats, composed largely of sphagnum, is rather common in more northern regions. *Sphagnum cuspidatum* grows to the water's edge in thick, sloping masses, either without the aid of other plants, or more or less supported by the underground stems of herbaceous plants, such as marshlocks and buck bean, and by woody heaths, such as Labrador-tea and laurel. At higher levels and nearer the dunes, *Sphagnum fuscum* grows vigorously around the bases of heath shrubs, salal, sweetgale, and cascara. It is found to less extent as alternating hummocks and depressions, or under the scattered and stunted trees of invading conifers. Characteristic members of the bog-plant community are cotton grass in wet depressions, ferns, pitcherplant, star-flower (*Trientalis* sp.), lily-of-the-valley (*Maianthemum bifolium*), white violet, and others. Of the mosses, the most common species are *Sphagnum cuspidatum*, *S. fuscum*, and *S. acutifolium* Ehrh. In remnants of pools occur *S. cuspidatum* and *S. apiculatum* Lindb., together with waterlily (*Nymphaea polysepala* (Engelm.) Greene) which is a native constituent in the lakes but is gradually being crowded out by the sphagnum that forms hummocks. Waterlily disappears almost entirely in the older and more mature parts of the bog.

In relation to the natural succession of bog vegetation in lakes the vertical profile sections show the following features:

- 0 to 29 inches, moss peat. The 5-inch surface material underneath thickets of heath shrubs, is dark reddish-brown spongy-fibrous *Sphagnum fuscum* peat which is moderately decomposed and strongly acid in reaction. It contains slightly decomposed leafy litter, mainly from Labrador tea, and coarse, woody underground sprouts of ferns. Below this is bright yellowish-brown, well-preserved moss peat derived from *S. cuspidatum* and *S. palustre*. This grades into reddish-brown, compact, and more or less laminated moss peat that has undergone an advanced degree of decomposition.
 - 29 to 48 inches, the upper part of the layer is reddish-brown fibrous sedge peat, in which the content of organic residue is low and rather evenly distributed. The deeper material is dark brown, somewhat heavier in texture, and contains reddish woody fragments from deciduous shrubs.
 - 48 to 60 inches, reddish-brown sedimentary-fibrous sedge peat, which is soft and dense. It contains some small woody debris, fine-textured organic sediments, and coherent fibers from rhizomes and roots of sedges.
 - 60 to 68 inches, dark grayish-brown sedimentary peat which is heavier in texture and more compact than the overlying material. On drying it has an amorphous colloidal appearance and a platy or lumpy structure, correlated with accumulations in standing water.
- The underlying mineral material consists of gray sand stained with organic matter and containing dull-brown root channels.

(30) ILWACO PROFILE

About 2 miles northeast of Ilwaco, Wash., are several areas of peat that have reached a comparatively mature stage, in which trees and shrubs are dominant and mosses are not advancing on the coniferous swamp forest. The cover of vegetation is similar to that described for the Clatsop profile. Much of the forest has been cleared, and the surface layer of woody peat has been burned, in the course of preparing the ground for planting cranberries.

The modified vertical cross section has the following features in relation to its former cover of natural vegetation.

0 to 17 inches, sedge peat, the upper part of which consists of dark-brown partly fibrous sedge peat containing charred woody fragments and granular residue. Between depths of 6 and 14 inches below the present surface, the material is yellowish-brown coarsely fibrous sedge peat which is compact and distinctly laminated or platy in structure. Below this the sedge peat is dark brown and contains woody material from shrubs and branches of trees. The woody components appear to be due to the work of beavers or may have fallen or floated in from the adjoining uplands when a lake occupied the depression.

17 to 45 inches, grayish-brown firm sedimentary-fibrous sedge peat which is sticky, owing to the presence of large quantities of organic sediments. This layer contains seeds of herbaceous plants and, at the deeper level, varying quantities of woody material and brown fibrous rhizomes. This would seem to indicate a shallow body of water, as an early stage, which was occupied by tussocky sedges, rushes, and small thickets of shrubs. The wet marsh tended to spread with the rising water level caused by dams constructed by beavers, but the marsh vegetation was ultimately replaced by trees, when the water level was lowered.

The underlying mineral substratum is loose sand containing root channels.

DISCUSSION

The several profiles identified in the northern Pacific coast section show clearly that the broader and primary distinctions between peat land are correlated with climatic and regional differences and corresponding differences in vegetation. Where rainfall is high, the organic material shows an acid reaction, and the area of peat has a more or less raised center. These characteristics develop independently of topographic conditions. On the other hand, alkaline and saline conditions in flat or depressed areas are the corresponding distinctions of organic materials and peat land in dry semiarid Pacific coast sections. Differences in morphological profile features and in stages of profile development are, however, correlated generally with differences in local conditions, such as land relief and drainage. Hence it is both possible and desirable to group the general profile characteristics within each section into two primary divisions—the series of peat layers in water basins and on soils—and to base types of peat land on more detailed textural differences or degree of decomposition of surface material, and on stage of maturity and conditioning local factors.

PEAT LAND IN THE PUGET SOUND BASIN

The Puget Sound drainage area lies in northwestern Washington. It is characterized by elevations ranging from sea level at Puget Sound to 14,408 feet on the summit of Mount Rainier in the Cascade Mountains. In general, the lower sections are flat alluvial plains, bordered by foothills, and the upper parts of the watershed are forest-covered areas with steep slopes. Several important streams have their sources in the western slopes of the Cascade Mountains and empty into Puget Sound.

The climate is mild, with short periods of freezing in the winter. July to September is generally the dry season. The heaviest precipitation occurs from October to April. The average annual precipitation ranges from 30 inches on the sound to more than 100 inches in the mountains, where most of it falls as snow (14).

Irrigation is practiced locally, but in general the rainfall is abundant during the growing season. Flooding, however, is often serious. The development of upstream storage reservoirs in the form of lakes and marshes would tend to reduce flood heights. Additional investigations in flood control are necessary as regards natural check dams, gullies, depressions, and the distribution and character of peat-forming vegetation existing in the upper reaches of the main streams on watersheds.

The Soil Survey Division, in cooperation with the Washington Geological Survey, has mapped 50,048 acres of peat land (25). Following is a discussion of pertinent studies of profiles of peat land in the valleys of Nooksack, Skagit, Stillaguamish, Snohomish, Green, and Puyallup Rivers. Data relating to these rivers are in part those set forth in the reports from the Chief of Engineers, United States Army, and published as House documents dealing with examination of rivers and harbors.

PROFILES IN THE NOOKSACK RIVER BASIN

The Nooksack River rises on the western slope of the Cascade Mountains in northwestern Washington and flows into Bellingham Bay, an arm of Puget Sound. Nearly all the Nooksack drainage basin is in Whatcom County. The watershed of the basin is in general mountainous and covered by forests. Elevations in the basin range from sea level to 10,750 feet at the summit of Mount Baker.

The annual average rainfall ranges from 31 inches at the coast to 114 inches on Mount Baker in the national forest. Most of the precipitation occurs in the mild winter season between October and April.

Nooksack River is steep and swift in the upper reaches. It is subject to floods and carries a rather heavy burden of silt and clay. Data on stream flow are meager, and no accurate determination has been made on the discharge of the river or its high- and low-flow values. The low-water flow of the river is generally ample to supply the occasional demands for irrigation during dry summers. Information on damages from floods has been collected recently by H. B. Carroll, Jr., county agricultural agent, and J. M. Adams, county engineer. Most of the floods are caused by heavy rainfall in the mountains, combined with the rapid melting of snow by warm westerly winds known as chinooks. Partial control of floods is considered possible by using natural sites and reservoirs near the boundaries of the watershed. Much of the flood waters in the valley can be retarded in the form of channel storage near the mouth of the stream.

Areas of peat land are very largely confined to the lower part of the valley. A few of them are flooded at times of high water, and over others silt and clay have been deposited to a depth of several inches. An approximate determination of the acreage has been made in the report of the Soil Survey Division on the Bellingham area (24). The soils mapped include 16,640 acres of peat land in Whatcom County. Some of the larger areas are west of Northwood; others are east of Custer, between Strandell and Enterprise, and in the highland near Mosquito Lake in T. 38 N., R. 5 E.

Between Blaine and Sumas, extensive areas of peat are located near the Canadian boundary. They have been severely burned over, leaving, in most places, an orange-colored ash. The tracts are re-

ported to have supported a characteristic growth of conifers and related shrubs, and in the more open places the cover of vegetation was predominantly sedges and cattail. Sphagnum bogs appear to have been present more or less centered within the marshes.

(31) BLAINE PROFILE

The wooded section of the peat area east of Blaine, Wash., was cleared of its timber and planted to oats. Profile soundings made along the road between R. 2 E. and R. 3 E., T. 40 N. and a quarter of a mile south of the Canadian boundary gave the following record:

0 to 15 inches, sedge peat, in which the surface material, disked and harrowed to a depth of 3 inches, consists of reddish-brown or yellowish-brown fibrous sedge peat, acid in reaction (pH 5), partly decomposed, air-dry, and lumpy. Below this the sedge peat is compacted to a more or less platy structure and contains many seeds of buck bean, some charred debris, and small woody fragments. In the deeper part of the layer the material is heavier in texture, more or less plastic and contains flattened rootstocks of cattail and a varying amount of organic residue.

15 to 20 inches, dark-gray diatomaceous sedimentary peat, predominantly of fine texture. It contains black well-preserved plant remains from horsetail, brown fibrous roots and rhizomes from tussocky sedges, and charred woody material, probably wind-blown.

The mineral substratum consists of gray clay and shows evidences that horsetail fern was a very common plant in the early stages of vegetation of the shallow lakes of this section.

(32) NORTHWOOD PROFILE

West of Northwood along Fishtrap Creek the peat area at one time supported a dense growth of sedges and other marsh vegetation and was wet and flooded during a large part of the year. This tract is at present drained and yields fair crops of pasture grasses.

Profile sections show the following features, indicating that the peat area was originally a wet marsh, submerged by the rise of the water level and in consequence supported the encroachment of an aquatic vegetation.

0 to 60 inches, diatomaceous muck. To a depth of 7½ inches the surface of the layer consists of cloddy moderately friable reddish-brown siliceous muck. Embedded in this material is a network of roots of growing plants and various quantities of charred woody material. It is underlain by gray diatomaceous sedimentary peat, which is acid in reaction (pH 5.5) and predominantly fine textured. This is underlain at a depth of 12 inches by a sharply demarked band of orange-colored iron-stained diatomaceous material that is water-laid in origin. In the deeper parts of the layer the content of organic matter is higher, and the material ranges from dark grayish-brown to blackish-gray diatomaceous sediments, with an admixture of fibrous components and woody fragments from willow.

The underlying substratum consists of dark-colored sandy gravel having a moderately acid reaction (pH 6). Artificial drainage is rather excessive, the water level being more than 4 feet below the surface. On account of the large quantities of siliceous remains of diatoms, the peat area is not well supplied with mineral nutrients.

(30) CUSTER PROFILE

East of Custer is an extensive area of peat land occupying a broad depression on the boundary of the Nooksack River drainage basin. The southern part of this area has been injured by fires which recur frequently. Springs and drainage water from higher lying land,

together with the developmental sequence of plant communities that spread and thus hindered natural drainage, are probably the principal factors in the development of this peat area. Precipitation was stored and gradually raised the water level of an original lake, in which the principal layers, that constitute the profile features of the deposit, were preserved.

Examples of the vegetation covering the Custer peat land are heaths, Labrador-tea, *Kalmia polifolia*, and salal, which are present in great numbers. Hummocks are formed by *Sphagnum fuscum*, *S. magellanicum*, and other mosses, with their associated cranberry vines and small herbaceous plants. Of the latter, round-leaved sundew, *Cornus canadensis*, *Trientalis arctica*, *Maianthemum* sp. and *Toffieldia* sp., still grow in undisturbed natural conditions, mostly around the heaths, but in places that have been changed by drainage or fire, the sphagnums are replaced, generally by species of *Polytrichum* and liverwort. Conifers are common. The trees are mostly young shore pines, forming dense groups irregularly mixed with *Tsuga heterophylla* (Rafinesque) Sargent, *Thuja plicata*, D. Don., *Pseudotsuga taxifolia* (La Marck) Britton, and a few birches (*Betula occidentalis* (Hooker) Sargent.) These trees characterize transitional stages, from bog to swamp forest, caused by fires and by lowering of the water level. The frequent occurrence of dead pines in burned-out depressions supporting sedges, cotton grass, tule, and species of liverwort and mosses (*Dicranum*, *Aulacomnium*, and others) is another indication of marked changes. In wet and more or less marginal depressions *Spiraea douglasii* and *Myrica* sp. form almost impenetrable thickets, and in small hollows, that are common between hummocks, western skunkcabbage grows, forming a very effective contrast.

In relation to the surface vegetation the vertical profile section shows the following features at a point 5 miles north and 1 mile west of Ferndale.

- 0 to 24 inches, moss peat, the upper 10 or 12 inches of which consist of reddish-brown fibrous partly decomposed and strongly acid *Sphagnum fuscum* peat containing fine rootlets and dark-colored woody rootstocks of heaths. This material grades into a dark-brown mixture of woody moss peat in which are a few stumps and roots of conifers and various-sized beaver-cut sticks.
- 24 to 156 inches, grayish-brown fibrous sedge peat which contains partly decomposed woody fragments, crumbles readily, and at greater depths is saturated with water.
- 156 to 180 inches, bright yellow-brown fibrous well-preserved *Hypnum* peat. This layer is sharply demarked and was formed in part by species of *Drepanocladus* and *Dicranum*. The material has a moderately acid reaction (pH 6) and retains the features of a dense mat that floated on open water.
- 180 to 210 inches, brown fine-textured more or less plastic sedimentary peat, which grades into olive-green organic sediments that developed from pond weeds, tape grass, and aquatic plants.
- The underlying substratum consists of bluish-gray sticky clay which is slightly alkaline in reaction (pH 7.5).

(34) MOSQUITO LAKE PROFILE

In the higher foothills, between Middle Fork and South Fork of Nooksack River near Mosquito Lake, a bog was investigated, that resembles in some respects the area of peat examined by the writer

in the Fraser River delta near Vancouver, British Columbia. An area of approximately 25 acres has been reclaimed to a very great extent. Large ditches have been cut through the bog to drain the water from springs and seepage into Bear Creek. The deposit has a comparatively deep layer of moss peat which is excavated in large blocks with specially shaped spades. This material is air-dried on the ground and is used in the commercial production of stable bedding, poultry litter, and slabs of moss peat for packing cut asparagus. The slabs are three-eighths or one-half inch thick and 9 by 12 inches wide. Sphagnum mosses evidently must have played an important role and continued to exist for a considerable period of time. They were only recently replaced by heath shrubs and a few scattered coniferous trees which reflect a physical environment altered, probably, by man. The bog occupies a depression that appears to be connected with Mosquito Lake. It is surrounded by a comparatively moist highland forest dominated by fir, balsam, cedar, hemlock, and pine. Vertical test borings, made in more or less central locations, gave the following record:

- 0 to 132 inches, moss peat. The material to a depth of 4 feet below the surface consists of bright-yellow or brown spongy-fibrous moss peat which is fairly compact, comparatively well preserved, strongly acid in reaction, and more or less free from roots, rhizomes, and woody material. At irregular intervals are white lenslike accumulations of sphagnum peat that developed in wet depressions, also thin bands of dark-brown moss peat characterizing a partial degree of decomposition. Below the 4-foot level the material is reddish brown, fibrous, moderately decomposed, and saturated with water. At greater depths the moss peat is loosely fibrous and yields methane gas; the material alternates with pockets of water, possibly as a result of secondary pools or in consequence of high water levels during a period when remnants of an open lake were overgrown with mosses. The peat is interlaced with reddish-brown branchlike fibers and roots of cranberry vines that appear to have formed a support for a series of floating mats of mosses, which later sank to the bottom.
- 132 to 144 inches, dark grayish-brown or olive-green organic sediments, moderately acid (pH 6) in reaction. The material contains a small admixture of fibrous plant remains and rhizomes from sedges that invaded the area.
- 144 to 192 inches, brown or yellow-brown *Hypnum* peat, including species of *Drepanocladus*. The material is comparatively well preserved and is neutral in reaction. The upper part of the layer appears to have been a quaking mat that covered open water during initial stages, and at the lower level the material contains twigs and branches from shrubs, also small woody fragments that may have been cut by beavers. It rests on a thin band of coarse-textured organic residue which grades into a dark reddish-brown mixture consisting of *Hypnum* peat, woody material, and rhizomes from tule and other sedges.
- 192 to 312 inches, grayish-brown sedimentary peat which is soft, structureless, more or less colloidal, and neutral in reaction (pH 7).
- At lower levels the organic sediments are of a distinctly mustard brown color, fine grained, and of cheesy character. Toward the bottom the material is green or olive green, neutral in reaction, and consists of oozelike organic sediments derived chiefly from soft small aquatic plants and microscopic organisms that constitute normally a free-floating plankton in lakes well supplied with mineral nutrient salts.

(35) VAN ZANDT PROFILE

The peat areas in the foothill district include, beside sphagnum bogs, a different type of organic deposit. About one-half mile north of Van Zandt and east of that town is a deposit which merits a word of description. It is a small body of open water comprising 2' or 3

acres, dotted with bluish-green patches of stonewort algae (*Chara* sp.). These aquatic plants form a close mat about 6 or 8 inches below the surface of the water and are active in the deposition of calcium carbonate as marl. Lime accumulates also upon floating pond weeds and herbaceous water plants, making them brittle. The annual settling of gray-colored and finely granular *Chara* marl has built up a deposit of lime that is probably several feet thick. The thickness of the marl bed and the characteristic features of the Van Zandt profile were not determined in detail.

PROFILES IN THE SKAGIT RIVER BASIN

Skagit River is the largest stream entering Puget Sound. It has its source north of the international boundary on the western slope of the Cascade Mountains in Canada. Two-thirds of its drainage area is included in national forests. Large stands of timber occur below an elevation of 6,000 feet. Above the timber line much of the upper area which extends to an elevation of 10,000 feet is characterized by snow fields and glaciers. In sharp contrast to the rugged mountains is the flat lowland or delta section near the coast.

The river and its main tributaries—Sauk and Baker Rivers—flow with erratic run-off through canyons, narrow valleys, and steep gradients. Natural reservoirs are lacking. In the main valley the river flows through a delta in two main channels and several minor outlets.

Precipitation is abundant, and irrigation is of no importance in the valley. However, Skagit River is subject to destructive floods that frequently cause great damage. They may occur at any time in the year when warm chinook winds from the coast melt glaciers and snow fields with great rapidity. Most of the flood damage occurs in the lower valley. Floods appear to have been the cause of complete channel diversion and may have traveled at one time through a large area of peat land west of Burlington, Wash. This depression appears to have been a diversion channel and later to have furnished flood storage during periods of inundation, thus acting in materially reducing overflow.

(36) BURLINGTON PROFILE

A series of observations were made on open ditches along a highway about 1 mile north and 2 miles west of Burlington, Wash. The peat deposit is shown on the map of the Soil Survey Division reconnaissance of the eastern part of the Puget Sound Basin (25). The area, which drains into Padilla Bay, has been under cultivation to grains and to a limited extent to vegetable crops, but at present it is used mainly for pasture and hay.

The following profile features were noted:

0 to 14 inches, sedge muck, the topmost 2 inches of which consist of dark grayish-brown mellow and granular organic residue. Below this and extending to a depth of 8 inches the material is of similar character but has a higher content of silt, probably brought in by flood waters, and a network of roots of the growing grasses. The underlying material is dark grayish-brown moderately firm and partly decomposed fibrous sedge peat. It has a platy or laminated structure, contains seeds of buck bean and other herbaceous marsh plants, and reacts moderately acid (pH 5.5).

14 to 60 inches, dark chocolate-brown or grayish-brown sedimentary-fibrous sedge peat which is layered and acid in reaction (pH 5). It contains seeds of various species of herbaceous plants and small crystals of some salt in excess. At variable depths, usually between 23 and 36 inches below the surface, the layer is stratified with stream-borne silt and clay. At the lower level the material consists of greenish-gray silty organic sediments which are slightly acid in reaction (pH 6) and show iron-stained root channels alternating with grayish-brown silty and clayey fibrous material. At greater depths the stratified layer contains greenish-gray clay, and toward the bottom the material resembles a mixture of organic residue and clay, having its origin probably in the waste of earlier floodwaters.

The underlying substratum consists of sticky bluish-gray clay.

The small areas of peat land near Belleville and Summit were not examined.

PROFILES IN THE STILLAGUAMISH RIVER BASIN

The Stillaguamish River is a comparatively small river draining a watershed of 630 square miles. One-third of the watershed is in Skagit County and two-thirds in Snohomish County. The river is formed by the confluence of two tributaries, North and South Forks, and it discharges through a delta into Port Susan and Skagit Bay of Puget Sound. North and South Forks have their sources in the secondary peaks and ridges of the Cascade Mountains and drain 302 and 257 square miles, respectively. Rainfall is heavy in the ridges, but snow fields are few, as the highest elevation within the drainage basin is less than 7,000 feet. The rugged topography of the basin does not lend itself to natural storage of water. Lakes for conserving rainfall and floodwaters are few and small, stream gradients are steep, and diversions of excess stream flow into marshes and bogs require further investigations. The natural cover of vegetation in the mountains, however, is reported to delay run-off appreciably. The middle and upper parts of the watershed are heavily forested and form parts of two national forests.

The basin shares the climate common to the Puget Sound section. The average annual rainfall ranges from 35 inches near the mouth of the river to more than 100 inches in the mountains. Sudden downpours flow over a considerable area in the valley during the winter, but floods are of short duration, local in character, and not serious.

(37) ROBE PROFILE

The course of South Fork River lies comparatively close to the southern side of the watershed. About 1 mile south of Robe, Wash., in sec. 18, T. 30 N., R. 8 E., an area of peat land occupies a depression in a flat plain resembling a terrace which the South Fork developed at an earlier period when it carried larger volumes of water than it does today.

On the margin of the peat area hemlock and cedar are common, forming a rather tall growth, but, owing to the action of fires, the vegetation may be characterized as a complex of conifers and shrubs, rather than as a succession from moss stages, through heaths, to swamp forest. Associated with the tree groups are alder, salal, cascara, and ferns, with *Spiraea* thickets developing more conspicuously in marginal zones. In more open areas the heath shrubs, *Ledum* and *Kalmia*, are present, together with hummocks of sphagnum dominated by *Sphagnum fuscum*.

The results of sounding vertical cross sections are as follows:

- 0 to 5 inches, dark grayish-brown partly fibrous and strongly acid moss peat, generally in an advanced stage of decomposition as compared with the spongy-fibrous moss peat typical of the hummocks. That the central part of the bog has been ravaged by fires at one time or another is indicated by charred debris at the lower level.
 - 5 to 30 inches, yellowish-brown or reddish-brown fibrous sedge peat, more or less felty matted and acid in reaction. The upper part of this layer contains leafy litter from heaths and woody roots from various shrubs, and in the lower part are small quantities of seeds of buck bean, together with organic sediments, rendering the material fairly soft and less pervious.
 - 30 to 72 inches, brown or grayish-brown sedimentary-fibrous sedge peat which is acid in reaction. Between depths of 32 and 36 inches is a thin seam of volcanic ash, and between depths of 60 and 70 inches the organic sediments contain an admixture of linear leaves of conifers and small woody fragments.
- The underlying material consists of gray fine sand mottled with black particles. It contains a few roots and some organic residue and is moderately acid in reaction (pH 5.5).

There are a few areas of peat in the North Fork Valley, and several large deposits lie close to Stillaguamish River near Bryant and south of Norman, Wash. The profiles of these peat lands illustrate a sequence of layers in water basins as well as on land, in the latter case enriching the mineral soils with organic matter, increasing the content of ground water, and promoting wet-marsh conditions. The details of the profile features have not been examined.

PROFILES IN THE SNOHOMISH RIVER BASIN

The Snohomish River is formed by the junction of two principal tributaries—the Skykomish, which drains an area of 840 square miles of the entire drainage basin that is 1,825 square miles in extent, and the Snoqualmie, with a drainage area of 690 square miles. The eastern part of the watershed is rugged, mountainous, and well forested. It has steep slopes in the upper reaches, which account for the suddenness of the run-off. The streams rise in the higher parts of the Cascade Mountains, where precipitation is heavy. They carry a large amount of silt, flow through a low-lying delta and marshes that are subject to inundation during the winter, and empty into an arm of Puget Sound at Everett, Wash.

Precipitation and temperature are affected by altitude and proximity to sea level. The amount and distribution of rainfall are similar to these features in the other river basins of Puget Sound, heretofore described. The winter season is mild, owing to the warm westerly winds blowing from the ocean. Well-sustained low-water flows, augmented by the snow which never entirely disappears from the higher peaks, occur between August and October, when precipitation is comparatively small. Damaging floods are of short duration, and usually they do not coincide with the growing season. Run-off from Snoqualmie River is reported to be much more uniform than that from the Skykomish, and from both the flow is greater in the summer when precipitation is least. It is estimated that erratic floods of major proportions may occur on an average of once every 5 years. There appears to be, moreover, a definite tendency for the occurrence of comparatively long, wet periods, followed by similar long periods of deficient precipitation. Examples of this are a

falling off of the recorded flow of Skykomish River near Index, Wash., and of Snoqualmie River near North Bend, Wash., as shown in tables 2 and 3. Mountain lakes, together with natural sites and depressions, are not uncommon, but satisfactory information regarding them is not available. They probably support peat-forming plant communities and if developed, would prolong run-off, add materially to the storage of water resources, and contribute to measures for protection against floods and erosion.

TABLE 2.—*Natural mean discharge of Skykomish River near Index, Wash.*¹

Year ended Sept. 30	North Fork (drain- age area 149 square miles)	South Fork (drainage area 355 square miles)	Year ended Sept. 30	North Fork (drain- age area 149 square miles)	South Fork (drainage area 355 square miles)	Year ended Sept. 30	North Fork (drain- age area 149 square miles)	South Fork (drain- age area 355 square miles)
	<i>Second- feet</i>	<i>Second- feet</i>		<i>Second- feet</i>	<i>Second- feet</i>		<i>Second- feet</i>	<i>Second- feet</i>
1912-----	1,060	2,350	1919-----	1,370	2,710	1926-----	1,240	1,650
1913-----	1,070	2,650	1920-----	1,330	2,220	1927-----	770	2,330
1914-----	1,240	2,330	1921-----	1,130	3,010	1928-----	1,140	2,720
1915-----	1,140	1,470	1922-----	1,550	2,120	1929-----	820	1,720
1916-----	720	2,840	1923-----	1,060	2,230	1930-----	811	1,600
1917-----	1,290	2,490	1924-----	1,070	2,120	1931-----	1,000	1,790
1918-----	1,170	3,000	1925-----	990	2,590			

¹ Figures from water-supply papers of the U. S. Geological Survey and published in House Document 258 (37).

TABLE 3.—*Natural mean discharge of Snoqualmie River near North Bend, Wash.*¹

Year ended Sept. 30	North Fork (drain- age area 105 square miles)	South Fork (drainage area 84 square miles)	Year ended Sept. 30	North Fork (drain- age area 105 square miles)	South Fork (drainage area 84 square miles)	Year ended Sept. 30	North Fork (drain- age area 105 square miles)	South Fork (drain- age area 84 square miles)
	<i>Second- feet</i>	<i>Second- feet</i>		<i>Second- feet</i>	<i>Second- feet</i>		<i>Second- feet</i>	<i>Second- feet</i>
1912-----	667	473	1919-----	682	627	1926-----	578	433
1913-----	698	473	1920-----	650	502	1927-----	770	600
1914-----	683	480	1921-----	812	719	1928-----	860	600
1915-----	520	334	1922-----	658	518	1929-----	530	430
1916-----	837	659	1923-----	649	551	1930-----	450	363
1917-----	728	549	1924-----	600	476	1931-----	552	431
1918-----	797	648	1925-----	723	626			

¹ Figures from water-supply papers of the U. S. Geological Survey and summarized in House Document 258 (37).

Included within the flood plain are several areas of peat land comprising a total of 11,908 acres. Their location is indicated on the Soil Survey Division maps of the Everett area, Washington (7).

In the Snohomish Valley, areas of peat land extend on both sides of the meandering river. They are subject to inundation. Floods, although of short duration, may cover parts of the valley floor with water to a depth of several feet, transforming them into a lake until the overflow recedes. Dikes and drainage ditches with floodgates, and in some places pumping equipment, facilitate quick removal of the waters, but these measures do not offer protection against major floods.

(38) SNOHOMISH PROFILE

Between Lowell and South Snohomish, Wash., test soundings generally record the following profile features in an area of peat land, parts of which are used for hay and pasture, potatoes, and corn. The soundings were made in sec. 22, T. 28 N., R. 5 E., near the intersection of Marsh road and John Davis road.

0 to 54 inches, sedge muck. The 8-inch surface material is under cultivation and consists of silty brownish-colored granular organic residue and lumpy clods and is moderately acid in reaction (pH 5.5). The material below this and continuing to a depth of 36 inches is yellowish-brown fibrous peaty muck compacted to a platy or laminated structure. It has a slightly acid reaction (pH 6) and contains many seeds of buck bean, rhizomes of rushes and tule, and woody fragments that may have been parts of a beaver dam. The material grades into sedge peat that is matted fibrous and porous. At the lower level it is grayish brown from an admixture of mineral sediments brought in by a flood of unusual character.

54 to 84 inches, brown sedimentary-fibrous sedge peat which is waterlogged and fairly dense. It contains bits of fine-fibered rootlets forming a flocculent and fluid mass that thickens with depth.

84 to 105 inches, gray soft sticky sedimentary peat which is slightly acid in reaction (pH 6.5). It contains black well-preserved fragments of horsetail.

Between depths of 108 and 144 inches is a fibrous mat of brown sedge peat interlaced with rhizomes of horsetail, representing a floating mat that sank to the bottom, and below this are a few logs of deciduous timber, mainly willow.

At a depth of about 156 inches the organic sediments are grayish brown, and they contain varying quantities of clay and drifted woody fragments, fibrous material, and bits of leafy tissue from pond weeds.

Below a depth of 200 inches the development in this part of the peat area largely represents clayey organic sediments that accumulated in an open lake.

(39) WOODRUFF PROFILE

Conditions on the east side of the river flood plain, between Monroe and Snohomish, are somewhat different. The peat area is not flooded to as great an extent as that on the west side of the river, and the profile is one-layered. It consists of a comparatively shallow deposit of sedge peat. Soundings were made in the northern part along the highway near Woodruff, Wash., in the southwest quarter of sec. 27. The peat area originally supported a cover of deciduous shrubs, and it is now a bluegrass pasture bordered by willows and *Spiraea* and bounded by low gravelly terraces and flat moraines. Its profile features may be described as follows:

0 to 36 inches, sedge muck, in which the 6-inch surface material is cultivated organic soil. It is brown friable more or less granular and acid sedge muck and is readily penetrated by roots of the growing grasses. Below this the material is matted-fibrous partly decomposed peaty muck which includes rhizomes of reeds, woody roots, and fragments from deciduous shrubs of various kinds, well-decomposed organic residue, and seeds from herbaceous plants. The material crumbles easily and has an acid reaction.

Below a depth of 36 inches the material is underlain by gray or bluish-gray sandy clay having a slightly acid reaction (pH 6.5). It contains particles of mica, brown roots from sedges, and black rhizomes from horsetail ferns.

The southern part of this peat area produces truck crops including lettuce, carrots, peas for canning, turnips grown for seed, and other vegetables. Surface fires have destroyed much of the cultivated organic soil and almost destroyed some of the wooden drains

that carry off hillside seepage waters of an alkaline reaction (pH 8). The peat of the disturbed Woodruff profile shows the following features:

- 0 to 60 inches, sedge peat, in which the 6-inch surface material is grayish-brown ashy somewhat woody fibrous sedge peat, acid in reaction, moderately decomposed, and developing to a granular residue. The material below consists of grayish-brown or dark-brown fibrous-matted partly decomposed sedge peat containing woody material, some of which is charred. Between depths ranging from 2 to 5 feet below the present surface, the layer is coarse fibred, waterlogged, loose, and has an odor of hydrogen sulphide. Toward the bottom the sedge peat is grayish brown, matted fibrous, partly decomposed, and contains woody material. The underlying substratum is gray sandy clay which is slightly acid in reaction (pH 6).

(40) SULTAN PROFILE

A relatively advanced stage in profile development, having distinctive features, occurs in an area of peat land on the north side of the Skykomish River Valley, at the foot of a steep slope. It originally supported a mixed swamp forest of hemlock, cedar, large alder, and dogwood, and an undergrowth of elderberry, vine maple, and other plants. A description of the soundings made on the south side of the road to Sultan, Wash., in sec. 3, T. 27 N., R. 7 E., is as follows:

- 0 to 30 inches, woody muck. In its present condition the surface material, to a depth of about 2 inches, consists of dark grayish-brown loose dry granular woody muck which is slightly acid in reaction (pH 6). The material below is very dark brown or black well-decomposed woody muck containing reddish-colored woody roots, white rootlets from herbaceous plants, and earthworm burrows, giving the soil a granular structure. At a depth of 18 inches, a perceptible change in color and composition marks the transition to a moderately decomposed litter of needles, leaves, woody fragments, and charred debris. It overlies dark grayish-brown woody-fibrous sedge peat which is compacted and has a coarse cloddy structure.
- 30 to 60 inches, grayish-brown sedimentary-fibrous sedge peat containing an appreciable amount of organic sediments, rendering the material fairly impervious although interlaced with rhizomes. Between depths of 52 and 60 inches, there is a fibrous mat which consists largely of black well-preserved rootstocks of horsetail fern.
- 60 to 108 inches, grayish-brown fine-textured sedimentary peat which is slightly acid in reaction (pH 6). The upper part of the layer is streaked with a matted litter (probably stream-borne) from coniferous trees. Below this the organic sediments are soft and waterlogged. Between depths of 72 and 108 inches the material contains bits of fibrous roots, woody fragments, and drifted timber that was deposited during a stage when the volume of water in the depression was unusually large.

(41) NORTH BEND PROFILE

Conditions in the Snoqualmie River Valley may be illustrated by an area of peat land about 1 mile west of North Bend, Wash. Thickets of *Spiraea* and tussocky sedges cover a depression in an old valley fill above Snoqualmie Falls. The relatively moist wooded margin is dominated by willow. The present vegetation is poorly developed and very likely is not similar to the original one. The density of the stand of *Spiraea* is to a very great extent determined by the action of previous fires. Areas of this kind are sometimes drained, cultivated, and later abandoned. The profile of this particular area of peat land has the following characteristics:

0 to 11 inches, sedge muck. The 8-inch surface material consists of very dark brown mellow granular crumbly sedge muck. It is acid in reaction (pH 4.5) and contains a vigorous growth of roots of the surface vegetation which interlaces at a depth of 9 inches below the surface. The underlying material is grayish-brown largely decomposed firm peaty muck which breaks into clods when dry.

11 to 60 inches, light-brown or brownish-gray sticky sedimentary peat. It contains seeds of buck bean, some fibrous components, chiefly rhizomes from sedges or tule, and, at lower levels, a relatively high content of drab clay. Between depths of 48 and 60 inches the material is more or less stratified, and bands of gray-brown organic sediments alternate with bluish-gray micaceous sand and record the effects of fluctuations in flood discharges during earlier periods.

The underlying mineral substratum consists of waterlogged coarse sand containing particles of mica. The material is slightly acid in reaction (pH 6.5).

Conditions nearer the coast appear to be favorable for the development of sphagnum bogs. Several areas of peat, which may be characterized as raised bogs, were examined in the smaller tributaries and creeks of younger valleys. The raised central part is not so conspicuous, however, as in the dome-shaped bogs of more northern cooler and moister districts.

(42) EDMONDS PROFILE

In the SE $\frac{1}{4}$ sec. 15, T. 27 N., R. 4 E., on the south side of the road from Edmonds and about 1 mile east of Alderwood, Wash., a bog occupies a depression surrounded by flat-topped low hills of glacial drift. Its surface rises appreciably toward the center and is more than 2 feet above the marginal border. The main part of the area is covered with a heath community, mostly Labrador-tea, and to less extent, *Kalmia polifolia*. Associations of hummock-forming mosses include *Sphagnum fuscum*, *S. magellanicum*, *S. rubellum*, and others. They are partly overgrown by cranberry, sundew, Canadian dogwood, and, at intervals, by lichens. In the narrow hollows are ferns and here and there small clumps of cotton grass and *Spiraea*. In the transitional zone to the margin of the bog there is a scattered growth of hemlock and white pine, and in the wooded border, shore pine is common, with hemlock, cedar, and an undergrowth of alder, salal, cascara, *Spiraea*, and a number of ferns (*Polypodium vulgare* L., *Adiantum pedatum* L., *Polystichum* sp.).

The vertical profile section may be described as follows:

0 to 15 inches, moss peat. Exclusive of the yellowish-brown practically undecomposed moss peat which occurs in hummocks a foot or more above the general surface, the material consists of a 3- or 4-inch layer of dark yellow-brown spongy-fibrous moss peat, slightly decomposed and strongly acid, grading into dark reddish-brown more or less matted-fibrous moss peat, interlaced with a network of rootlets and containing leafy litter from heaths and ferns. This material is underlain by yellow-brown very little decomposed fibrous moss peat that was probably developed by *Sphagnum apiculatum* in open water.

15 to 60 inches, reddish-brown fairly impervious plastic sedimentary-fibrous sedge peat, corresponding to a stage when a mixed community of aquatic and marsh vegetation was growing over an open body of water. At a depth of 36 inches below the surface the material contains an admixture of charred woody debris, apparently wind-blown. It is underlain by a thin band of brownish-yellow volcanic ash. Between depths of 38 and 60 inches the organic sediments are more or less plastic, dense, and compacted. They range in color from dark gray to grayish black and grade into a grayish mixture of varying quantities of brown fibered material, charred residue, and gray sand.

The underlying mineral material consists of gray sandy and gravelly drift slightly acid in reaction (pH 6.5) and containing, at the contact line, roots and rhizomes of sedges.

The profile features in the wooded marginal parts have a thin surface layer of brown leafy litter over yellowish-brown or brown moss peat which is partly decomposed and about 8 inches thick. This is underlain by material having characteristics essentially the same as those described in the profile above at a depth of 15 inches.

It is probably needless to add that commercial development of this type of peat deposit is not justified, because of the comparatively shallow layer of moss peat and the unfavorable compaction and plasticity of the underlying sedimentary-fibrous sedge peat.

An account of other characteristic profiles of bogs and marshy peat areas in King and Snohomish Counties is given in Handbuch der Moorkunde (9). Some of the bogs, such as those at Cottage Lake and Esperance Lake, or at Evans Creek, have a relatively thicker layer of moss peat, but the most important deterrent to their utilization is the difficulty of excavating material from lakes that are deep and cannot be drained.

PROFILES IN THE GREEN RIVER BASIN

Green River rises in the Cascade Mountains at an elevation of 5,000 feet. It drains a basin of about 480 square miles, nearly all of which is in King County. The upper parts of the watershed are mountainous, with steep ridges and wooded slopes that were among the first to suffer from deforestation. The river meanders through an alluvial plain that is subject to overflow during floods.

In common with most of the river basins of Puget Sound, the basin of Green River is characterized by a climate that is mild, owing to the prevailing westerly warm winds and the abundant rainfall. The mean annual precipitation on the higher, cooler slopes of the mountains is generally much greater than that in the lower, western part, near Puget Sound.

Records of stream flow are almost wholly lacking, but fragmentary information is reported to indicate that the flood discharges per square mile of Green River, gaged for a drainage area of 235 square miles, are much greater than for Puyallup River. The principal reasons for this, doubtless, are that the forest cover has been removed and that much of the precipitation is in the form of rain rather than snow. The area in the valley actually under water during the high floods of winter has been estimated as ranging from about 9,500 to 11,500 acres. Nearly all of this land lies north of Auburn and Kent, Wash.

Peat land in the valley is very largely confined to the alluvial plain between the present Green River, which is still known locally as White River, and the mouth of Black River, formerly the outlet of Lake Washington. The peat areas are subject to inundation. A large proportion of this land is under cultivation and produces cauliflower, green peas, lettuce, Chinese cabbage, spinach, and other vegetables. The crops are shipped to the city markets direct by truck. Some irrigation is practiced, mostly by sprinkler systems.

(43) ORILLIA PROFILE

On the Kent-Renton highway are uncultivated areas, most of which are wooded jungles of alder, willow, and elderberry, and cultivated areas which produce annual truck crops including lettuce and cabbage. Profile soundings were made in sec. 19, T. 23 N., R. 5 E., near Orillia, Wash. A vertical cross section in the wooded area shows the following features:

- 0 to 24 inches, woody muck. Under virgin conditions the material has very little leafy litter over the surface. To a depth of 10 inches it consists mainly of brown mellow well-decomposed woody residue. A moderate content of silt, derived from overflows, gives it a grayish cast. Woody roots of deciduous shrubs permeate the layer below a depth of 10 inches and are underlain by slightly acid compacted woody peat which assumes a coarse lumpy or granular structure when disturbed. An abrupt transitional layer, at a depth of 18 inches, marks a band of gray volcanic ash, moderately to slightly acid (pH 6) in reaction and stained with rusty-red spots and root channels. It rests on comparatively well preserved leafy litter derived mainly from alder.
- 24 to 36 inches, light-brown sedimentary-fibrous sedge peat, mottled with small black roots and parts of rhizomes from horsetail fern. The material in this layer is waterlogged, slightly acid in reaction (pH 6.5), and contains drifted timber at the lower level.
- 36 to 96 inches, brownish-gray heavy-textured sedimentary peat composed of slightly disintegrated roots and bits of rhizomes from marsh plants, organic sediments derived chiefly from aquatic vegetation, and thin bands of volcanic ash and silty material. The layer has a more or less laminated appearance, conforming probably to major fluctuations of flood discharges and volcanic disturbances.
- The underlying mineral substratum consists of bluish-gray fine sandy clay which is water-laid, plastic, and alkaline in reaction (pH 7.5-8).
- The water level in open ditches is about $1\frac{1}{2}$ feet below the surface, and the water is neutral or slightly alkaline in reaction (pH 7 to 7.5).

Profile sections of peat areas nearer Renton, Wash., have been described in *Handbuch der Moorkunde* (9).

PROFILES IN THE PUYALLUP AND ADJACENT RIVER BASINS

The Puyallup River has its source on the western slopes of Mount Rainier, the summit of which is at an elevation of 14,408 feet and is occupied by the largest glaciers in the State. These glaciers are small in comparison with their former extent when they merged with a mass of ice that filled Puget Sound Basin. They exist today in a shrunken form and are slowly receding and possibly disappearing. Puyallup, White, Cowlitz, and Nisqually Rivers are fed by these glaciers, and they are heavily charged with drift and silt. Puyallup River drains a basin of about 958 square miles, flows through a valley of rolling lowland and marshy flats, and empties into Commencement Bay at Tacoma, Wash. Glacial and stream erosion have rendered the upper part of its basin very rugged and irregular.

Floods in the Puyallup Valley are generally caused by a combination of heavy rainfall and high temperatures that melt masses of snow and ice on the mountains. Table 4 gives a list of the crest discharges of the river at Puyallup, Wash., for each year since the establishment of the Geological Survey gage at that point in 1915, together with the estimated discharges of two destructive floods prior to that year. The records show that severe floods may be expected once in 4 to 6 years, and they also indicate a falling off of the flow.

The deficiency is in general typical of conditions that have obtained on the watersheds of the Snoqualmie, Skykomish, and other rivers which have their headwaters on the western slopes of the Cascade Range. This deficiency is also indicated by such records as are available of the discharge of Upper Klamath Lake in Oregon.

TABLE 4.—*Crest discharges, Puyallup River at Puyallup, Wash.*¹

Date	Crest discharge	Run-off per square mile	Date	Crest discharge	Run-off per square mile	Date	Crest discharge	Run-off per square mile
	<i>Second-feet</i>	<i>Second-feet</i>		<i>Second-feet</i>	<i>Second-feet</i>		<i>Second-feet</i>	<i>Second-feet</i>
November 1906.	2 36,600	2 40.0	Dec. 30, 1920---	24,900	27.2	Nov. 25, 1927---	25,400	27.8
November 1909.	2 27,500	2 30.0	Dec. 13, 1921---	35,600	39.0	Jan. 13, 1928---	20,700	22.6
Dec. 22, 1915---	22,300	24.4	Dec. 24, 1922---	17,000	18.6	June 14, 1929---	8,610	9.4
Mar. 10, 1916---	18,400	20.1	Jan. 6, 1923---	31,000	34.0	Mar. 25, 1930---	8,390	9.2
Dec. 18, 1917---	40,500	44.3	Feb. 12, 1924---	21,700	23.7	Apr. 1, 1931---	19,800	21.7
Dec. 14, 1918---	20,100	22.0	Dec. 23, 1925---	15,800	17.3	Jan. 12, 1932---	11,900	13.0
Jan. 23, 1919---	36,500	39.9	Oct. 16, 1926---	14,500	15.9			

¹ Records from U. S. Geological Survey as published in House Document 153 (32).

² Estimated.

The height and discharge which future floods, due to such circumstances, would attain is a matter of speculation, but it does seem that, with glaciers receding, considerably smaller floods may be expected. Conservation of water resources is consequently of great importance. The general benefit resulting from the restoration of vigorous covers of native vegetation and from the use of peat areas or any suitable site for storage, diversion, or holding back surface waters would, therefore, justify further research.

The principal tributary of the Puyallup is the White (Stuck) River which enters the Puyallup near Sumner, Wash. On both sides of the river valley, between Sumner and Auburn, are several cultivated areas of peat land. Intensive farming methods have been especially practiced in growing head lettuce and peas. Other crops grown for city markets are tomatoes, cabbage, celery, rhubarb, and Evergreen blackberries. Pasturage is good, but the trend of production, partly on account of the proximity to Tacoma, Wash., seems to be to truck crops.

(44) DIERINGER PROFILE

On the east side of White River, at the foot of a steep escarpment, vertical soundings were made near Dieringer, Wash. Owing to the fact that an excess of salts is beginning to accumulate, the area of peat is used now chiefly for pasture. A description of the profile features as they appear in sec. 12, T. 20 N., R. 4 E., about one-half mile south of a power station, is as follows:

- 0 to 10 inches, grayish-brown or dark-brown granular and mellow sedge muck which is moderately acid in reaction (pH 5) and readily penetrated by roots of grasses. The 5-inch surface material is mottled with small white clusters of calcium sulphate crystals. Gray saline incrustations are common on exposures of the layer in open ditches, in which water, 3 feet below the surface, has a slightly alkaline reaction (pH 7.5).
- 10 to 114 inches, chocolate-brown fibrous partly decomposed sedge peat, which grades into reddish-brown and at a depth of 36 inches into yellowish-brown coarsely fibrous matted sedge peat. Below a depth of 40 inches the layer is saturated with water and gives off an odor of hydro-

gen sulphide. Between depths of 90 and 110 inches is a thin band of volcanic ash, and the sedge peat beneath contains black rhizomes and roots of horsetail ferns (scouring rush).

- 114 to 132 inches, light-brown sedimentary peat which darkens rapidly on exposure to air. The material is mottled with charred woody debris, probably wind-blown and indicative of upland forest fires during early periods. Roots and rhizomes of horsetail fern are fairly abundant. The reaction of the organic sediments varies between neutral and alkaline (pH 7.5 and 8).

The underlying mineral material consists of gray fine sand, nearly alkaline in reaction, and is sharply demarked from the organic sediments above it.

The area of peat land on the west side of White River extends northward toward Kent. It has varying dimensions, and it is probable that water-borne silt carried by the river has been deposited over the greater part of the area. The river has an appreciably reduced gradient and at one time must have afforded sites for ponding.

(45) AUBURN PROFILE

A large proportion of the peat land in the vicinity of Auburn, Wash., is under cultivation and is considered one of the more valuable areas for general farming as well as for various truck crops. Head lettuce and green peas are the principal vegetables grown in an area of peat about 1 mile southwest of Auburn. Profile soundings were made near the highway and close to the boundary of the Green River watershed. The morphological features of a vertical section are characterized by the following:

0 to 10 inches, sedge muck, of which the 6-inch surface material consists of a mixture of silty overflow and organic residue. It developed from well-decomposed sedge peat and breaks up under slight pressure to a fine-granular condition. The material below is moderately acid and contains woody roots and fragments of a former cover of deciduous shrubs, charred residue, earthworm cavities, and some insect burrows.

10 to 24 inches, a transitional layer abruptly marking the separation of the cultivated horizon from a brown somewhat woody-fibrous sedge peat which is moderately decomposed and slightly acid in reaction. The material is compacted and more or less laminated, but readily breaks up to coarse structural components.

24 to 36 inches, brown sedimentary-fibrous sedge peat containing various kinds of seeds, including buck bean, and small pieces of undetermined woody material, probably the result of work by beavers. The layer is somewhat plastic and impervious because of the predominance of organic sediments.

The underlying mineral substratum consists of gray compact sand which is neutral in reaction. Accumulations of salts have not occurred.

(46) OLYMPIA PROFILE

Southwest of the Puyallup watershed are several areas of peat which have more than local interest. They are in Pierce County and belong more properly to the drainage basin of Nisqually River. The information and data pertaining to these peat areas are meager, especially as to topography and water supply, but the profile features are of assistance in arriving at some idea of the character of moss peat deposits within the climatic influences of the Olympic Range and the inlets of Puget Sound.

Soundings were made with the assistance of L. K. Couch, of the Bureau of Biological Survey, in an area of peat about 4 miles east of Olympia, Wash., near the Willamette Meridian. The natural vegetation was originally a heath community of *Ledum* and *Kalmia*, with

sphagnum forming low hummocks. The plant cover was scalped and burned off. Parts of the surface layer of peat material were cultivated for celery; others were sanded and planted to cranberry vines. Within the last 10 years the area has been abandoned and now supports various weeds and pasture grasses, thickets of *Spiraea* and sweetgale, and a young growth of pine.

The features which characterize the profile are as follows:

- 0 to 12 inches, moss peat. To a depth of 5 inches the surface material consists of light-yellow coarse sand which is moderately acid in reaction (pH 6), and is interlaced with many roots of the growing cover of vegetation. The material below is reddish-brown fibrous partly decomposed moss peat which is strongly acid in reaction (pH 4.5), and contains rhizomes of cotton grass.
- 12 to 24 inches, gray-brown slightly decomposed matted-fibrous sedge peat which is compacted and moderately acid in reaction (pH 6). The coherent network of roots and rhizomes has the characteristics of a mat that floated on open water.
- 24 to 54 inches, very dark brown fairly impervious sedimentary-fibrous sedge peat containing black organic residue and, at a depth of 32 inches, a 2- or 3-inch band of yellowish-gray mineral material which is probably volcanic ash. Beneath this is sedimentary-fibrous sedge peat, in which the organic sediments are sticky and plastic.
- 54 to 228 inches, blackish-brown sedimentary peat containing, in the upper part of the layer, different quantities of gritty sand washed in by floods. Between depths of 60 and 84 inches the material contains brown rhizomes derived in part from tule, and it varies in degree of compactness. At a depth of about 90 inches the material is waterlogged and is predominantly a porous network essentially like that of a fibrous mat from sedges that encroached on open water. It contains seeds of buck bean and elytra of insects. It has a moderately acid reaction (pH 6). At still greater depths, between 150 and 160 inches, the organic sediments are banded by yellow-brown *Hypnum* peat that is nearly neutral in reaction. Toward the bottom, the sediments are dense, plastic, include wind-blown winged seeds of shore pine, parts of insect wings, diatoms, and other debris. The color of this material is predominantly green or olive green.

The underlying mineral substratum is sharply demarked and consists of greenish-gray sand which is neutral in reaction.

It will be noted that this profile, although comprising four main layers, is in reality very complicated. It records, from time to time, changes in environmental conditions, in water levels, vegetation, and organic materials which at the respective periods ranged from peat to muck and varied greatly in composition, texture, and color. The present vegetative cover of a peat area and the physical character of the organic material, to such depths as growing roots may penetrate, may be of comparatively limited value for assuming an apparent benefit to agriculture.

PEAT LAND IN THE UPPER COLUMBIA RIVER BASIN OF WASHINGTON AND IDAHO

The main part of the upper Columbia River drainage area lies between the Continental Divide and the Cascade Range (35). The mountain areas of the watershed are covered with forest. The open country is to a large extent a high rolling tableland, dissected by many dry stream valleys and gorges. The principal headwaters are Columbia River proper and Kootenai River, both of which rise in British Columbia, and Clark Fork and Spokane River which drain large parts of Idaho.

The climate in the basin is characterized by well-marked wet and dry seasons. The average annual rainfall ranges from a maximum of about 100 inches in the Cascade Range to a minimum of 6 inches in the central part of the basin. In general, the least precipitation occurs during the growing season of July and August. The low flows of the river and its tributaries are generally in winter, and floods, caused by warm rains on the headwater snow fields, occur during May and June, at times even later. Irrigation is the outstanding problem in the central part of the Columbia River Basin. In many localities the utilization of both surface waters and underground waters is becoming of increasing importance. Development of water storage in basins and depressions and the spread of peat-forming vegetation might tend to have an equalizing effect on flows and increase ground-water storage by percolation. Further studies are necessary to determine upstream conditions of the Spokane, Clark Fork, and Kootenai Rivers, especially in relation to any marsh, swamp forest, and bogs on topographic sites, that would promise the control of water resources and act as natural detention reservoirs.

Profile soundings, carried on in connection with this study, have been limited to areas of peat land in the Spokane and Kootenai River Basins. Most of the organic soils of this section are immature in development because of abnormal or poor drainage, the resistant character of the parent peat materials, and the insufficient time having yet elapsed for their decomposition where such factors as aeration, nutrient salts, and soil micro-organisms are most favorable. On that account differences between types of peat soils have been made largely on the basis of the plant remains from which the parent material is derived. The criterion in differentiating the characteristics attained by organic soils or muck is, in large part, the stage of decomposition or relative maturity which the parent material has reached in the climate of this section.

PROFILES IN THE SPOKANE RIVER BASIN

Spokane River is a minor tributary of Columbia River and drains an area of only 6,000 square miles. It rises in Coeur d'Alene Lake, Idaho, and flows westward, discharging into Columbia River near Lincoln, Wash. The lake provides a regulating effect, as it has a low-water elevation of 2,117 feet, and the highest water level it has been known to reach was 2,134.7 feet. The upper part of the drainage basin is rugged, with steep-sided valleys and peaks rising into areas of perpetual snow. A large part of it is heavily forested and included in the Coeur d'Alene National Forest. In the lower part the drainage basin is in places a comparatively wide and level valley, in which conditions of semiaridity prevail. Comparatively long stream-flow records (extending back to 1891) are available for the Geological Survey gaging station at Spokane, Wash. (14). The mean annual discharge contributed by the stream is estimated at 8,000 cubic feet per second.

Areas of peat within this drainage basin occupy depressions in drift and in basins of volcanic rock. The Soil Survey Division has mapped 6,208 acres of peat land in Spokane County, Wash. (38).

The areas of peat land in Spokane County, derived from organic accumulations, range in depth from a few inches, in the basaltic

scabland section, to more than 16 feet in the peat land at Newman and Eloika Lakes, surrounded by residual soils. In the scabland section, as well as in the valley of Little Spokane River, some of the original lakes and ponds have become partly filled with silt and in part with diatoms and later with peat from aquatic and marsh vegetation.

(47) CHENEY PROFILE

About 2 miles south of Cheney, Wash., on the Chapman Lake road, is an extensive plainlike depression which is poorly drained and surrounded by outcrops of basalt. The only portions cultivated are narrow margins which provide pasture during part of the year. The greater part of the area has the appearance of a cattail and tule marsh, with an undergrowth of bur reed (*Sparganium* sp.), smartweed (several species of *Polygonum*) and patches of various algae. *Hypnum* mosses are present in places, together with small shells of mollusks. The water level is about 8 inches below the surface, giving a slightly acid reaction (pH 6.5). The profile features have the following characteristics:

- 0 to 12 inches, a 6- to 7-inch layer of very dark brown or nearly black tule muck which is granular, friable, and readily penetrated by many roots of growing plants. Below this is a partly fibrous peat derived from tule, cattail, and soft-tissued herbaceous plants. The material is dark brown, more or less compact, and tends to become lumpy when dry.
- 12 to 30 inches, dark-gray, silty, and very compact sedimentary peat containing an admixture of diatoms and volcanic ash at the lower level and grading into gray silt which ranges from neutral to slightly alkaline in reaction (pH 7-7.5). Root channels of sedges appear in this layer.

(48) SPOKANE PROFILE

A deeper deposit in basaltic rock outcrop is in the city of Spokane, Wash., between Arthur and East Second Streets. This area of peat has the appearance of occupying a craterlike depression or possibly a deeply entrenched canyonlike stream course that was isolated by gravelly filling. The peat land is of importance locally, on account of its commercial use in supplying organic matter for the improvement of mineral soils. The original vegetation was one resembling that of the natural marshes within the scabland. Exposed layers in the excavated part and profile soundings show the following characteristic features:

- 0 to 25 inches, sedge peat. The upper 2 inches of the layer consist of very dark brown largely decomposed granular residue containing charred debris from surface fires. This material is slightly acid or neutral in reaction and overlies light grayish-brown silty moderately decomposed fibrous peat which is air-dry, compacted, and more or less laminated. Seeds of buck bean are present below a depth of 10 inches, indicating that the material developed largely from an open sedge marsh that included tule and herbaceous plants.
- 25 to 45 inches, a thin band of volcanic ash and a sharply demarked reddish-brown *Hypnum* peat which is porous in structure, interlaced with rhizomes of sedges, and furnishes evidence of a mat that floated on the surface of a former lake.
- 45 to 72 inches, dark grayish-brown fibrous or felty-fibered sedge peat grading into yellow-brown felty-fibrous sedge peat that contains an abundance of seeds of buck bean and rhizomes of reedlike grasses.
- 72 to 84 inches, greenish-brown sedimentary-fibrous sedge peat. Although the material is compact and of heavy texture, it contains a fairly large quantity of rootstocks of waterlily, leafy material from pond weeds, and seeds of buck bean. It is moderately acid in reaction (pH 6-6.5).

84 to 240 inches, greenish-brown or brown organic sediments which are coarse textured but smooth at the upper level. The material is noticeably high in content of leafy parts from pond weeds and tape grass (*Vallisneria* sp.) and seeds of waterlily, buck bean, and other aquatic plants. Between depths of 150 and 168 inches the leafy fragments are lime incrustated and brittle, but no excess of calcareous material was deposited as marl. At a depth of 185 inches the organic sediments are olive green and contain maroon-colored rhizomes of tule. Between depths of 200 and 240 inches the sedimentary peat is a dark olive-green, fine-textured, plastic, and jellylike mass which is neutral in reaction. It is chiefly the product of organisms that constitute a free-floating and suspended microscopic life of lakes and ponds.

The underlying mineral substratum consists of a sharply demarked layer of volcanic ash, neutral in reaction.

From the point of view of ecological concepts this profile illustrates an ecologic succession or historic change which can be separated into a series of stages in water leading from the original peat-forming aquatic plant community on the bare volcanic ash substratum to the comparatively stable, higher type of vegetation on the present surface. The movement does not seem to have been disturbed or halted by any unfavorable climatic change. The basin remained for a long time a body of open water with fluctuating levels. It is only within a comparatively recent period that lowered water levels and drought conditions, more prolonged than formerly, are definitely indicated by the profile. But until a time scale is established, based possibly on varvelike laminations, there is no way to date any of the events that led to the development of the profile, except to estimate the duration at several thousand years.

(49) SALTESE PROFILE

One of the larger areas of peat land in the Spokane River Valley is the Saltese marsh which is a poorly drained depression in the flood plain. The sloping margins are in part under cultivation and support an open stand of oats, and in part are used for hay and pasture. The central inner part of the marsh is predominantly covered by a growth of sedges, cattail, tule, and aquatic plants. Thickets of willows and poplar border the open ditches, and the water in the ditches stands at a depth of about 1 foot below the surface. It has a dark amber color and an acid reaction (pH 5).

Profile soundings were made on the east side of the marsh about 500 feet from the road. They record the following features:

0 to 36 inches, sedge peat. Under present virgin conditions the surface material consists of dark-brown peat containing many brown fibrous roots and rhizomes, in different degrees of decomposition. In cultivated margins the material, to a depth of 8 inches, consists of dark grayish-black well-decomposed sedge muck which is strongly acid in reaction (pH 4) and contains an excess of salts that appear as incrustations on the surface and are brought up largely through evaporation. The material is lumpy when wet but on drying breaks into small clods and granules. Below the plowed level is brown partly decomposed felty-fibered sedge peat containing a crystalline salt. Between depths of 14 and 30 inches the layer has a comparatively high content of organic colloids. It is distinctly heavy textured, dense, somewhat platy in structure with well-defined jointing planes, and contains plant remains from cattail and tule and crystals of some salt. The lower part is more fibrous, chocolate brown, fairly compact, saline, and acid in reaction (pH 5).

36 to 156 inches, brown or grayish-brown tule rhizomes and plant remains from aquatic vegetation. The material ranges in reaction from moderately

acid to neutral (pH 6 to 7). Between depths of 60 and 84 inches the layer includes brown finely fibered sedge peat resembling a mat that was formed and floated during a rise of water level.

- 156 to 180 inches, brown sedimentary peat, generally amorphous, plastic, and neutral in reaction. It contains a few fragments of light-brown rhizomes, and in the lower part it assumes an abrasive character, owing to the presence of mineral matter similar to pumice and volcanic ash.

On the west side of the marsh, parts of the peat near the margin are excavated and used as a source of organic matter for soil improvement, with doubtful results. The apparent benefit to agriculture from the development of the Saltese marsh does not seem to be significant. The improvement of such areas of peat land for cultivated crops is undesirable. A greater benefit to the general public is to be derived from the restoration of this area to its original water level and to its preservation as a wildlife reserve.

Other large areas of peat, ranging in depth from 14 to 16 feet, are mapped by the Soil Survey Division (38) at both the head and foot of Newman Lake in T. 26 N., R. 45 E., and at the southern extension of Eloika Lake.

(50) NEWMAN PROFILE

At the southern end of Newman Lake soundings were made near the floodgate in the southeastern quarter of sec. 11, in an area sodded with bluegrass and used chiefly for pasture. Water at the floodgate has an alkaline reaction (pH 8), whereas that in a dug hole, about 2 feet below the surface, is acid (pH 5). Vertical cross sections show the following features:

- 0 to 24 inches, sedimentary peat. The upper part of the layer, to a depth of 5 inches, consists of dark-gray silty granular organic residue which is strongly acid in reaction (pH 4) and saline. It contains an appreciable quantity of roots of growing grasses and grades abruptly into reddish-brown sedimentary and diatomaceous peat which is lumpy and dry at a depth of 8 inches but is slightly fibrous and dark grayish brown or brown between depths of 13 and 24 inches.
 - 24 to 120 inches, brown or yellow-brown fibrous sedge peat. This material is acid in reaction and is mottled with black well-preserved rhizomes of horsetail fern or scouring rush near a depth of 60 or 70 inches. Below that level the material is coarsely or felty fibrous, matted, acid in reaction (pH 5), and evidently formed a quaking mat that floated on the lake surface as a result of rising water levels.
 - 120 to 192 inches, olive greenish-brown sedimentary peat which is slightly acid in reaction (pH 6.5). The upper part of the layer contains an abundance of fine rootlets, derived from an overhanging mat, and seeds of waterlily; the lower part is green, is distinctly laminated and varve-like, and contains leafy material from pond weeds and water plants, embedded in an ooze derived from microscopic organisms.
- The underlying mineral substratum is sharply demarked and consists of light-gray slightly acid (pH 6) medium fine sand overlying coarser gray sand.

(51) ELOIKA PROFILE

The southern extension of Eloika Lake is surrounded by low stony moraines, in which granitic boulders are abundant. The bordering vegetation consists mainly of poplar, willow, and *Spiraea* thickets, occupying a wet marginal depression. The surface is practically level toward the center and has a cover of young aquatic plants, of which the most prominent are species of *Ceratophyllum*, *Myriophyllum*, *Potamogeton*, *Polygonum*, and *Lemna*. A surprising feature is the partly decomposed stubbles of oats. This crop is reported to have been sown about 2 years ago, when the lake bed was sufficiently dry

for shallow cultivation. At present the water, in a dug hole, stands about 1 foot below the surface and has an acid reaction (pH 5). It is of the greatest interest to observe that within a period of 2 years the natural process of successional development of vegetation has resumed the restoration of plants native to the peat area and will continue to reestablish an equivalent cover if the disturbing cause ceases.

A description of profile soundings made in the NW $\frac{1}{4}$ sec. 15, T. 29 N., R. 43 E., is as follows:

- 0 to 12 inches, sedge peat. The topmost 3- to 5-inch layer of material consists of black finely granular well-decomposed residue or muck developed from sedge peat. The organic soil is slightly acid in reaction and very low in content of plant roots. Below this is dark-brown felty-fibered sedge peat in an advanced degree of decomposition, compacted and tending to be crumbly. This material rests on a thin band of firm brownish-gray volcanic ash having a moderately acid reaction (pH 6).
- 12 to 40 inches, grayish-brown or black diatomaceous sedimentary peat. The upper part of the layer contains moderate amounts of clay from eroding floods and breaks into small lumps with angular fracture. Between depths of 34 and 40 inches the material contains volcanic ash and different amounts of rhizomes.
- 40 to 96 inches, more or less fibrous charred sedge peat and charred woody residue. The latter is probably wind-blown material from forest fires, but the former suggests local burning and may indicate a dry period. Between depths of 48 and 72 inches the sedge peat is partly fibrous and contains plant remains from horsetail fern, and the material below is yellowish-brown or straw-colored coarsely fibrous matted sedge peat which is slightly acid in reaction (pH 6) and characteristic of a floating-mat stage.
- 96 to 160 inches, greenish-brown sedimentary peat which is somewhat fibrous in the upper part and contains seeds from herbaceous marsh plants. Beneath this are olive-green ooze-like organic sediments which give a neutral reaction and are varved or laminated in structure. Leafy material from pond weeds and other water plants is present in abundance in the lower part of the layer.

The underlying mineral material consists of light-gray soft gritty clay over boulder drift.

Deer, swan, and waterfowl were seen in sheltered places of this peat area. The facts brought out in the profile section indicate the advisability of abandoning its agricultural use. In the light of present economic conditions, the greater benefit would be derived from setting it aside as a wildlife reserve. The organic soil of this area is immature in development, because soil-forming processes cannot continue the progressive decomposition and modification of the more resistant parent peat material into organic residue (muck) or the formation of new chemical compounds and their translocation to a horizon of enrichment which marks, in a general way, the lower limit of water percolation from the surface and the relative maturity attained by an area of peat in a given regional climate.

In Kootenai County, Idaho, the Soil Survey Division, in cooperation with the Idaho Agricultural Experiment Station, has mapped 4,992 acres of peat land (21). Within the limitations of time and funds available, the profile features of these deposits could not be examined.

PROFILES IN THE KOOTENAI RIVER BASIN

Kootenai River rises in British Columbia near the source of Columbia River, but it flows in an opposite direction, paralleling the Continental Divide, and enters the United States at the Idaho

and Montana corner of the international boundary. The stream drains 19,450 square miles of mountainous country, of which only 1,075 square miles are in Idaho. It flows along a short curved course and empties into Columbia River a short distance from the mouth of Clark Fork River in Canada.

In Idaho the valley of the Kootenai widens from 2 to 3 miles at Bonners Ferry and is rather marshy. During floods of maximum record, the water at Bonners Ferry was 35 feet above low-water level, whereas in normal years the range in water level varied around 25 feet. There are areas of low peat land exposed to damage by floods, but the duration of many floods is probably slight, and excessive losses to crops have not occurred as yet.

The actual extent and distribution of peat land lying within the Kootenai Valley of Bonner and Boundary Counties, Idaho, are not known. Only a few areas of peat have been examined, within the limit of time available, with the aid of officials of the University of Idaho and the agricultural college at Pullman, Wash. Of the several profile studies it seems appropriate to present the following records:

(52) BRADLEY PROFILE

Among the sandy hills in Bonner County, Idaho, about 3 miles south and 1½ miles west of Naples, is a small depression, approximating 20 acres, known locally as Bradley Lake. It is generally under water and the native vegetation comprises several species of *Hypnaceae* and aquatics, among them *Aulacomnium*, *Drepanocladus*, *Amblystegium*, stonewort, pond weeds, waterlily, and other plants. *Hypnum* peat is excavated in large blocks during periods of low water level, spread for air-drying, and sawed into slabs that are three-eighths or one-half inch thick, 9 inches wide, and 12 inches long. The slabs are shipped to California for use in the packing sheds of asparagus growers.

Profile soundings were made about 500 feet from the shore in open water and gave the following details:

0 to 18 feet, *Hypnum* peat. In the central part of the lake the water is clear, alkaline in reaction (pH 8), and ranges in depth from 3½ to 4 feet. Below is a layer of light yellowish-brown fibrous well-preserved *Hypnum* peat which is more or less compacted in its upper part. The material is neutral in reaction. Toward the bottom it grades imperceptibly into loosely fibered brown or dark-brown peat which is moderately decomposed and neutral in reaction (pH 7).

18 to 19 feet, a dark-brown mixture of *Hypnum* peat and jellylike organic sediments that are chiefly the product of pond weeds and water plants. The reaction of this material is neutral.

In profile soundings near the margin of Bradley Lake the organic sediments are grayish brown and contain seeds of reedlike grasses and granular carbonate of lime from blue-green algae, particularly species of *Chara*.

The underlying mineral material consists of sand which is of a dull-gray color at a depth of 9 feet below the surface.

(53) PETERSON PROFILE

Another area of peat in the sand hills of Bonner County was examined about 2 miles south of Naples. It is known locally as the Peterson marsh, and the center of it is a small lake. The margin of

the depression is surrounded by sedges, forming a quaking mat as they encroach on the open water. Nearer the center of the lake are floating mats of *Hypnum* mosses, with patches of herbaceous plants, such as marshlocks, buck bean, yellow waterlily, pond weeds, and small floating plants that give the water a greenish tint. The water is neutral in reaction.

Profile soundings were made in the sedge marsh, but, owing to time limitations, samples from the lower part were taken only from every second foot below the surface. The most prominent features of the profile are the following:

0 to 84 inches, *Hypnum* peat, the surface material of which consists of a very thin mixture of sedge and *Hypnum* peat, finely fibered and dark grayish brown in color. Below this is light yellow-brown fibrous *Hypnum* peat which is 6 inches thick and penetrated by roots of growing sedges. This, in turn, is underlain by a 5-inch layer of grayish-brown partly decayed fibrous sedge peat containing an admixture of *Hypnum* peat. Between depths of 12 and 48 inches the material consists of yellowish-brown well-preserved *Hypnum* peat containing a very small amount of plant remains from sedges. Below this is a water pocket, in which loose *Hypnum* peat is intermixed with finely fibered sedge rhizomes. Between depths of 60 and 84 inches the material is comparatively pure *Drepanocladus* peat which is yellow brown, fine fibered, matted, and practically undecomposed. The lower part contains a few rhizomes of sedges and small woody fragments.

84 to 96 inches, grayish-brown partly decomposed felty-fibered sedge peat. At the lower level it contains varying quantities of seeds from herbaceous marsh plants and a small quantity of organic sediments.

96 to 252 inches, olive greenish-brown more or less colloidal sedimentary peat. The material is somewhat coarser in texture between depths of 144 and 156 inches, owing to the presence of fragments of rhizomes and roots embedded in the soft ooze-like sediments. It grades into olive-green sedimentary peat which is gelatinous in character, mottled with reddish-colored plant remains, and neutral in reaction.

The mineral substratum consists of very fine sand.

The profile reveals a relatively impure layer of *Hypnum* peat and indicates obvious changes in the development of the peat deposit. Most of the changes are in the upper part and reflect an alternation between communities of sedges forming a mat of sedge peat and *Hypnum* mosses that produced floating mats of moss peat. It may very well be that in certain periods the mats of *Hypnum* peat sank into the water and remained there, whereas mats of sedge peat, undergoing more readily a degree of partial decomposition by bacterial organisms (8) developed methane and other gases, floated again to the surface, and persisted until the competing mosses gradually became the essential peat-forming community by more rapid growth and response to conditions.

(54) KOOTENAI PROFILE

In the wide valley of the Kootenai River between Kenney and Whites, Idaho, the topography is for the most part smooth and flat. The more favorable areas of peat have been cleared of their original cover of sedges and put under cultivation. Hay, potatoes, vegetables, and other crops are grown with good yields. A description of the profile soundings that were made on an unreclaimed peat area in sec. 12, T. 63 N., R. 1 W., in Boundary County, is as follows:

0 to 36 inches, the surface material consists of light-brown or yellowish-brown slightly decomposed fibrous sedge peat which breaks up readily

to a crumbly condition. It contains varying amounts of silt, as a result of the flood discharges of the stream. At the lower level the material is more coarsely fibrous and contains rhizomes of horsetail fern.

- 36 to 108 inches, *Equisetum* peat. The upper part of this layer is gray silty *Equisetum* peat of firm consistence, mottled with many black roots of horsetail fern. Between depths of 48 and 60 inches the material is free from mineral matter, coarsely fibrous, porous, matted, blackish brown in color, well preserved, and slightly acid in reaction (pH 6.5), indicating a dense, exclusive growth of scouring rush during a period of time in which stream flow carried very little silt, and flood velocities were greatly reduced. From a depth of 60 to 108 inches the *Equisetum* peat is grayish brown, heavier textured, less permeable, and contains an amount of silt which increases with depth. The material at the lower level grades into silt mottled with rhizomes and fine black rootlets of horsetail fern and contains particles of mica and fine sand. It is slightly acid in reaction (pH 6.5).

The underlying mineral material consists of gray silt which is compact and somewhat sticky. It contains a few roots and rhizomes of horsetail.

It is interesting to note the first record of the occurrence of a peat layer derived from horsetail fern. Pure *Equisetum* peat is rather rare and appears to be confined to northern regions. Southward it occurs much more often intermixed with *Hypnum* peat and less frequently with sedge peat. The value and uses of the material are not well known. It is extremely resistant and like *Hypnum* peat shows little progress to organic soil development.

(55) HARPER PROFILE

Near the international boundary several areas of peat land occurring on slopes of the river valley, have reached a forest stage. The seepage waters appear to be supplied with mineral nutrients. The native vegetation is largely spruce, cedar, hemlock, and balsam fir, with an undergrowth of alder, mountain-ash, red-osier dogwood, *Spiraea*, and a ground cover including ferns, Canadian dogwood, and small patches of *Hypnum* and *Sphagnum* mosses. Slope wash has not set in, but natural drainage lines are flowing across the surface of the peat area. Profile soundings were made near Harper in Boundary County, in a forested peat area between secs. 29 and 30, T. 65 N., R. 2 E. Following is a description of a vertical cross section:

- 0 to 20 inches, woody peat. The characteristic covering of forest litter is very thin and is limited in composition to foliage. The material below it consists of chocolate-brown granular mellow woody peat which is acid in reaction. Roots and mycelium of wood-destroying fungi bind the material to a considerable depth. Woody fragments and woody roots of trees and shrubs predominate at the lower level.
- 20 to 48 inches, dark grayish-brown or brown woody sedge peat, moderately decomposed and slightly acid in reaction (pH 6). The material is more or less compact but crumbles when disturbed. Between depths of 36 and 40 inches is a layer of olive-green silty material consisting of organic sediments, rhizomes of sedges, and seeds of herbaceous plants. It represents, obviously, an interval during which flood waters were high and carried silt. Fluctuations in water supply changed the preceding shrubby sedge marsh to a dominantly sedge community which, later, was again replaced by shrubs and ultimately by forest.
- 48 to 84 inches, olive-green silty organic sediments. In the upper level, this layer contains rhizomes and roots from sedges, woody material, and leafy fragments. Between depths of 60 and 72 inches the organic sediments are dark gray and silty, and they contain seeds from herbaceous plants. Between depths of 72 and 84 inches is a water pocket which contains a loose mixture of small woody fragments, conifer needles, bits of bark,

and other material that apparently was carried by increased run-off and heavy floods.

The underlying mineral substratum consists of coarse loose greenish-gray sand which is slightly acid in reaction (pH 6.5).

DISCUSSION

The changes which this and other profiles suggest indicate that the vegetative cover of marshes, bogs, and swamp forests can hold back more floodwater and more of the excessive silt load carried into streams than can denuded land, and thus promote infiltration, reduce erosion, and prolong the time of run-off. Through many centuries there has been built up in this manner a deep store of ground water which is of major importance in the maintenance of ponds, lakes, and large rivers in valleys and the chief source of springs, small streams, and tributaries in minor headwater areas. There are many acres of drained peat land in the United States in a condition of dryness unsuitable for cropping, in which the stoppage of drainage outlets would lead to the restoration of wetness and native vegetative cover. Thus the beginning could be made of reestablishing and storing a supply of ground water that might be of great benefit to adjacent mineral soils and of value also during periods of relative drought.

SUMMARY AND CONCLUSIONS

In order to determine what relationship, if any, peat land might have to the problem of conserving the water resources of the Pacific coast region in the combined interests of irrigation, control of salinity, and stream-flow regulation, a study has been made of various peat areas in California, Oregon, Washington, and northern Idaho.

There are many areas of marshy lakes, bogs, and swamp forests throughout the Pacific coast region, that, in their natural condition, had a high degree of practical utility as conservers of water supplies and as natural feeding grounds of migratory birds and wildlife. Most of them have peat profiles that are important historical records of the original environmental complex. They have diagnostic value, and hence indicate not merely previous conditions and the process of plant successions by which nature forms and recovers areas of peat, but they serve also as a basis of determining how peat land should be utilized, if the best scientific and practical results are to be obtained.

It has been shown that during recent years the Pacific Coast States have received an annual precipitation markedly lower than the recorded average. Changes in rainfall appear to be more or less cyclic in character, and the ground-water table has receded to a point foreshadowing water failure as a growing crisis. Present scientific information is not sufficient to determine the length of time during which low precipitation, lowered ground-water levels, and drought will continue or when they will recur. Fluctuating changes in water supplies of the past are reflected in the profile features of peat land, but drought conditions seem to have been less prolonged in past periods than at present.

Information is given in detail concerning the genesis and intrinsic physical characteristics of peat profiles, the relation of their composition to the present cover of vegetation and to historical ecologic antecedents, the modifying conditions that determine the develop-

ment of organic soils and their general productivity for crops, the uses of peat resources in connection with the commercial production of peat and muck as organic matter for soil improvement, and the conservation of surface waters and ground-water supplies.

From the information at hand it appears that heavy losses and deterioration of peat land have been caused in recent years, notably in the Klamath Basin and in the southern Pacific section, by excessive drainage, the spreading injury by "alkali" and salt accumulation, damage from fires, wind erosion, and reclamation of peat land of doubtful agricultural value.

To forestall a critical water shortage in the coastal States and to increase water supplies, the restoration of water levels and original cover of vegetation or an approximation to it would prove an invaluable step. The inhibiting conditions modifying the productive capacity of peat land may well be regarded as a major argument in favor of the control of water supplies and the conservation and better use of peat resources.

As water is a factor that ultimately limits the productive capacity of soils of the Pacific coast region, it is suggested that areas of peat in valleys and boundaries of watersheds be made the subject of further study, especially for effective use during the period when restoration of the natural cover of vegetation is under way. It cannot be denied that adequate protection of peat deposits and their native cover render them valuable for storage reservoirs, for national benefits as reserves for wildlife, as resources of organic matter, or for any combination that would equalize stream flow, reduce floods and consequent erosion, and impound and conserve water supplies.

The data obtained in this study may be useful as a partial basis for the retirement of submarginal areas of peat land that are deteriorating and abandoned, difficult to drain or irrigate, clear, and protect from overflow, or have profile features unfavorable to agricultural production. To bring more peat land under cultivation appears to be undesirable under present economic and critical ground-water conditions. These hazards in the West must bring some consideration of the necessity of withdrawing areas of peat land from unsuitable agricultural and industrial uses, and allowing them to produce a type of native vegetation that would offer a barrier to flood waters and silting, absorb rainfall, impound water supplies, and increase the water content of the ground by percolation.

By coordinating the activities of various State and Federal agencies, many areas of peat land may be developed and restored as conservers of water supplies. Water is the critical resource in the Pacific coast region. It is particularly urgent in dealing with the problem of the cyclic recurrence of dry periods, and the progressive aridity caused by the sinking of ground waters to lower levels.

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